

Steadman, Shandelle et al.

**Research Report**

## Assessment of economically attractive low-carbon solutions across India's transport, building and agriculture sectors

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Report

# Assessment of economically attractive low-carbon solutions across India's transport, building and agriculture sectors

Shandelle Steadman, Elizabeth Tan, Laetitia Pettinotti, Tony Kamninga,  
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# Acronyms

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<b>BAU</b>	business as usual
<b>BEV</b>	battery electric vehicle
<b>CEA</b>	Central Electricity Authority
<b>CEEW</b>	Council on Energy, Environment and Water
<b>CGIAR</b>	Consultative Group on International Agricultural Research
<b>CH<sub>4</sub></b>	methane
<b>CIMMYT</b>	International Maize and Wheat Improvement Center
<b>CNG</b>	compressed natural gas
<b>CO<sub>2</sub></b>	carbon dioxide
<b>CO<sub>2e</sub></b>	carbon dioxide equivalent
<b>EPA</b>	Environmental Protection Agency
<b>EU</b>	European Union
<b>EV</b>	electric vehicle
<b>FAME</b>	Faster Adoption and Manufacturing of Electric Vehicles
<b>GDP</b>	gross domestic product
<b>GEF</b>	Grid Emission Factor
<b>GHG</b>	greenhouse gas
<b>GIZ</b>	German Development Corporation
<b>GST</b>	goods and services tax
<b>HDT</b>	heavy-duty trucks (>12 tonnes)
<b>ICE</b>	internal combustion engine
<b>IEA</b>	International Energy Agency
<b>IFC</b>	International Finance Corporation
<b>ILO</b>	International Labour Organization
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>IRENA</b>	International Renewable Energy Agency
<b>KII</b>	key informant interview
<b>N<sub>2</sub>O</b>	nitrate oxide
<b>LCV</b>	light commercial vehicle
<b>LDT/LDV</b>	light-duty trucks/ light-duty vehicles (<3.5 tonnes)

<b>LNG</b>	liquefied natural gas
<b>MAFW</b>	Ministry of Farmers' Welfare
<b>MDT</b>	medium-duty trucks (3.5-12 tonnes)
<b>MoEA</b>	Ministry of External Affairs
<b>MoEFCC</b>	Ministry of Environment, Forest and Climate Change
<b>MNRE</b>	Ministry of New and Renewable Energy
<b>MOP</b>	Ministry of Planning
<b>MoRTH</b>	Ministry of Road Transport and Highways
<b>MOSPI</b>	Ministry of Statistics and Programme Implementation
<b>MtCO<sub>2e</sub></b>	metric tonne of carbon dioxide equivalent
<b>NITI Aayog</b>	National Institution for Transforming India
<b>NIUA</b>	National Institute of Urban Affairs
<b>NRDC</b>	National Research Development Corporation
<b>NSFDC</b>	National Scheduled Castes Finance and Development Corporation
<b>OEM</b>	original equipment manufacturer
<b>PMUY</b>	Pradhan Mantri Ujjwala Yojana
<b>PSL</b>	Priority Sector Lending
<b>PV</b>	photovoltaic
<b>RADP</b>	Rainfed Area Development Programme
<b>RBI</b>	Reserve Bank of India
<b>SCC</b>	social cost of carbon
<b>tCO<sub>2e</sub></b>	tonne of carbon dioxide equivalent
<b>UK</b>	United Kingdom
<b>UNEP</b>	United Nations Environment Programme
<b>UNFCCC</b>	United Nations Convention on Climate Change
<b>UNFPA</b>	United Nations Population Fund
<b>US</b>	United States
<b>WEF</b>	World Economic Forum
<b>WHO</b>	World Health Organization
<b>WorldGBC</b>	World Green Building Council
<b>WRI</b>	World Resources Institute



# Executive summary

In emerging market and developing economies such as India, significant mobilisation of private capital is necessary to meet climate targets and shift to a low carbon development pathway. A large proportion of this private investment is expected to come from private developers, consumers and financiers. However, one barrier is a lack of well-identified investment opportunities.

To generate evidence that could help in addressing this barrier, in this report we conduct a bottom-up assessment and compile league tables of the cost and carbon-saving potential of a wide range of low-carbon measures that could be adopted in the Indian transport, building and agriculture sectors by 2030, instead of their traditional business as usual alternative. Furthermore, we provide an aggregation of the findings to determine the cost and emissions savings that could be made if the measures were adopted and invested in at scale across India.

We find several economically attractive measures across all three sectors that both are cost-effective by 2030 and provide emissions

reductions. In the transport sector, these include electric light duty trucks; three-, two- and then four-wheeler electric vehicles (EVs); and medium-duty trucks. In the building sector, they include cool roofs using reflective paint. In the agriculture sector, they include zero till seed drills; no tiller planting; cold storage – solar; solar pumps; solar-powered drip irrigation – sugar; and solar-powered drip irrigation – vegetables.

If all of these measures were deployed at scale, using ambitious but realistic rates of deployment, it would result in cost savings of INR 29 trillion, and emissions reduction of 1.1 billion tonnes of carbon dioxide equivalent (CO<sub>2</sub>e) by 2030. The transport sector provides the largest contribution – at 68% of emissions savings, or 717 million tonnes of CO<sub>2</sub>e reduction. Most of the cost-effective transport measures are related to EVs, which showcases how innovative technology costs have come down in recent years. Table ES1 shows the potential economic savings and emissions reductions associated with selected low-carbon measures across the transport, building and agriculture sectors.

**Table ES1** Potential economic savings and emissions reductions associated with selected low-carbon measures across the transport, building and agriculture sectors

Sector	Measure	Per Unit				At Scale		
		Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)	Total emission savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs by 2030 (crore INR)	Total economic costs by 2030 (million USD)
Agriculture	No Tiller planter	-59	0.13	-461	-5,530	3.34	-154,132	-18,665
Agriculture	Cold storage – solar	-13,396	176	-76	-913	0.07	-557	-67
Transport	LDTs/LDV's (<3.5T)	-1,937	39.05	-50	-595	80.62	-399,901	-48,426
Transport	3-wheeler EV	-795	22.4	-35	-426	120.56	-427,877	-51,814
Agriculture	Solar pumps	-426	12.06	-35	-424	42.21	-149,273	-18,076

Sector	Measure	Per Unit				At Scale		
		Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)	Total emission savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs by 2030 (crore INR)	Total economic costs by 2030 (million USD)
Transport	2-wheeler EV	-126	3.65	-35	-416	293.65	-1,017,027	-123,158
Transport	4-wheeler EV	-1,128	37.44	-30	-362	139.71	-420,911	-50,971
Transport	MDTs (3.5–12T)	-2,245	106.9	-21	-252	82.52	-173,292	-20,985
Agriculture	Solar powered drip Irrigation – Sugarcane	-38	22.64	-2	-20	22.64	-3,848	-466
Agriculture	Solar powered drip Irrigation – Vegetables	-19	28.73	-1	-8	28.73	-1,857	-225
Building	Cool Roofs – Reflective Paint (m <sup>2</sup> )	-0.01	0.07	0	-1.441	245	-2,931	-335
Agriculture	Alternate Wetting & Drying	8	22.08	0	4	513.08	11,440	1,385
Agriculture	Rotavator	31	59.5	1	6	115.8	5,984	725
Agriculture	Paddy straw chopper	63	59.49	1	13	115.77	12,287	1,488
Buildings	Commercial Green Buildings (m <sup>2</sup> )	0.6	0.5	1	13	24.61	2,691	326
Agriculture	Happy seeder	76	59.55	1	15	115.9	14,727	1,783
Agriculture	Reaper binder	140	59.74	2	28	116.26	27,306	3,307
Building	Residential Green Buildings (m <sup>2</sup> )	0.48	0.13	4	44	17.18	6,316	765
Transport	Buses (9m, 12m, 13.5m)	2,227	344.92	6	77	380.67	245,797	29,765
Agriculture	Baler	713	59.33	12	144	115.46	138,706	16,797
Building	LPG Cookstoves (Fuel Switching – Biomass to LPG)	36	2.63	14	163	3.91	5,324	645
Transport	HDTs (>12T)	11,590	422.11	27	330	1,179.25	3,238,025	392,112
Building	Commercial Solar Rooftop (kW)	1.3	0.02	84	1,010	0.1	822	100
Building	Residential Solar Rooftop (kW)	7	0.02	433	5,193	0.11	4,849	587

Source: Authors (for data sources see Appendix 1)

Note: Green corresponds to a measure that has a cost saving (negative value) and emissions saving compared with the BAU measure by 2030 and therefore has a greater cost to emissions benefit ratio (negative value); orange is for measures that over their lifetime rather than to 2030 have a cost saving (negative value) and emissions saving compared with the BAU measure; red corresponds to no economic savings over 2030 or lifetime (positive value). Exchange rate used for 2023, \$1 = INR 82.579 as per exchange-rates.org

We also found several other measures that, while not cost-effective by 2030, become cost-effective over their respective lifetimes. These additional measures, which include agriculture sector measures such as alternate wetting and drying; building sector measures such as commercial and residential green buildings and commercial and residential solar panels; and transport sector measures such as electric buses, do have the potential to reduce emissions further, by an additional 936 million tonnes, if deployed at scale. However, they require a more far-sighted outlook if being considered for investment.

We recognise that not every segment of Indian society is in a position to invest in low-carbon measures. Households on a low income and women within those households, in particular, may not have the finance, or the collateral to access finance, or even the agency to make investment decisions. Although this report considers the potential gender and social inclusion implications only qualitatively, we acknowledge that this is an area where public policies could step in, as there are substantial welfare implications for

each avoided unit of emissions. Some measures, such as electric buses or liquified petroleum gas cookstoves, may not be considered cost-effective over the near term but should be promoted as they contribute to substantial emissions savings and reduced pollution. This has impacts on all individuals' health and livelihoods and particularly women on a low income.

Given that demand across these key sectors in India – transport, building and agriculture – is projected to rise over the next few decades, this provides an ideal opportunity to shift private investors' capital towards low-carbon investments. The evidence generated in this report can therefore support the Reserve Bank of India, commercial banks and private investors' decisions to invest in the identified low-carbon opportunities. If these decisions and investments in low-carbon solutions are made at scale across India, this could put the country on a path to low-carbon development and could support India's pledge to cut its emissions by 1 billion tonnes by 2030 and reach its 2070 net zero emissions target.

# 1 Introduction

India is currently the third largest energy-consuming country in the world and the third largest global emitter of carbon dioxide (CO<sub>2</sub>) after China and the US (IEA, 2021; Gupta et al., 2022). Over the past decade, India's emissions have been trending upward, and they are projected to continue rising, highlighting the critical role the country plays in global decarbonisation.

Alongside this, India is particularly vulnerable to the impacts of climate change. If global temperatures go beyond 2°C as projected (UNEP, 2023), it is estimated that there could be a fourfold increase in the number of people exposed to severe hazards in India by 2050 (Gupta et al., 2022). Furthermore, India has high vulnerability to the impacts of climate change (NDGAIN, 2024). India's climate vulnerability undermines progress on development and poverty alleviation (Chakravarty et al., 2024). With 44% of the population already living on less than \$3.65 a day in 2021, India's climate policy needs to address the threefold challenge of reducing greenhouse gas (GHG) emissions while simultaneously reducing its vulnerability and achieving its development goals (World Bank, 2024a).

Given its development gap, India is yet to build the infrastructure it needs to meet its demand, and its future emission profile depends on buildings and factories that do not yet exist, and vehicles and appliances that have not been yet bought (IEA, 2021; WEF, 2021). Therefore, India has the potential to achieve its growth using low/no emissions technology, and to follow a development pathway that is more sustainable, through its own efforts and given the decreasing costs of clean energy technologies (IEA, 2021; WEF, 2021). As such, going forward, exploring low-carbon development pathways will be crucial.

However, emerging markets and developing countries such as India will not be able to finance the large-scale investment needed to meet their climate targets without the mobilisation of significant additional private investment. A large proportion of this investment is expected to be needed for capital-intensive clean energy assets and low-carbon solutions, and a large share of the private capital over the next decade is expected to come from private developers, consumers and financiers (Songwe et al., 2022). For example, financial institutions have a significant role to play in the climate transition through offering innovative financing products for a range of green investments. However, one of the main barriers to attracting this private investment is the lack of well-identified investment opportunities (Songwe, et al., 2022).

Scholars in India have developed low-carbon transition pathways for key sectors (see in particular Energy Innovation LLC and WRI, 2022; NITI Aayog, nd). However, there is a lack of granular information on the most cost- and carbon-effective low-carbon solutions that could realistically be adopted across different sectors. The aim of this report is therefore to generate an evidence base on potential investment opportunities by identifying economically attractive clean energy and low-carbon measures across three sectors in India – the transport, building and agriculture sectors – that provide emissions reduction benefits that could help mobilise private equity held across India and shift it to support this low-carbon development path.

The low-carbon measures we focus on are those likely to be adopted, scaled and financed by the same private capital holders identified earlier:

developers, consumers and financiers. As such, the evidence base has the potential to help these stakeholders make investment decisions that lead to increased adoption of the most cost- and carbon-effective opportunities across sectors, and thereby shift the way households' and firms' private equity is invested. Given the role of financial institutions, this evidence can also inform Indian financiers about the specific low-carbon opportunities that they could offer innovative financial products for, and it could inform the design of specific financial products, such as green mortgages, green loans, energy efficiency financing, etc., that are tailored to meet the needs of those looking to invest in these measures.

The Reserve Bank of India (RBI) can play a crucial role in facilitating the availability of green finance through policy frameworks and incentives, and regulations such as green finance taxonomies (for better identification of sustainable investment opportunities), green credit guidance (e.g. dual interest rates with a lower rate for low carbon projects) and green deposit (e.g. lower cash reserve ratio on green deposits) (AFI, 2021; RBI, 2021; IEEFA, 2023; New Economy, 2023).

Specifically, the RBI can use the evidence generated in this report to inform the type of projects that could be further included in its sub-targets under its Priority Sector Lending (PSL). The RBI PSL incentivises commercial bank lending towards certain projects, including green ones and could take into account the evidence presented in this report for updating of its priority sub-targets in the housing, agriculture and renewable energy sectors (RBI, 2021).

In this report, we compile league tables of the cost and carbon-saving potential of a wide range of low-carbon measures that could be adopted in the transport, building and agriculture sectors by 2030 and provide an aggregation of the findings. We further contextualise these low-carbon measures by considering their potential gender and social inclusion implications. Section 2 provides more detail on the Indian context; Section 3 outlines the methodology used and Section 4 presents the findings showing the potential economic and emissions savings. In Section 5, we discuss the potential beneficiaries – owners and users – associated with the measures and the inclusivity of the measures, before Section 6 concludes.

## 2 Context and scope

In 2016, India ratified the Paris Agreement under the United Nations Convention on Climate Change (UNFCCC) and in 2022, in its updated Nationally Determined Contribution, it committed to reducing its emissions intensity by 45% below 2005 levels by 2030 (MoEFCC, 2022a). Furthermore, at the 26th Conference of the Parties to the UNFCCC, the prime minister of India announced several other targets to be achieved by 2030. These included meeting 50% of India's energy requirements from renewable sources by 2030, reducing the total projected carbon emissions by 1 billion tonnes until 2030 and, in the longer term, achieving net zero emissions by 2070 (Shankar et al., 2022).

India's fast-growing population is expected to increase from 1.37 billion in 2019 to 1.59 billion in 2040 (IEA, 2021). This is expected to translate to increased energy demand, which in India is primarily fossil fuel-based: fossil fuels make up around 89% of the country's primary energy consumption (Ritchie and Rosado, 2024). Therefore this surge in energy demand is likely to result in increased GHG emissions, which is not in line with India's emissions reduction aspirations. As a result, the decisions and policies implemented within the next decade to 2030 will be key, as India must focus on low-carbon sectoral development. In this report, we focus on three of the key sectors that are expected to experience a surge in demand as a result of the rising population – transport, building and agriculture – and highlight the cost- and carbon-effective measures that could be adopted within them. The combined growth of population and economy will increase demand on transport networks, buildings and food systems; to meet existing and emerging

needs, new investments will be necessary in low-carbon measures at scale across these sectors to encourage low-carbon development.

### 2.1 Transport

India's transport sector caters to over a billion people and connects people to jobs and public services, boosting economic productivity and contributing significantly to the country's gross domestic product (GDP). It accounts for 10% of the country's total energy consumption. Freight transportation is the highest contributor to this consumption: trucks cause 45% of emissions from road transport by trucks (MoEFCC, 2021; IEA, 2021). Passenger road transport has also increased dramatically over the past few decades, with two-wheelers and four-wheelers contributing to the largest share of passenger energy (Kamboj et al., 2022). The rise in travel among Indians, along with larger volumes of freight transport, has led to transport becoming the fastest growing energy end-use sector (IEA, 2021).

While energy contributed 73% of India's total GHG emissions in 2019, transport contributed 12% of the country's energy-related emissions. This makes it the third largest contributor to the country's energy-related emissions, after the power and industry sectors (Climate Transparency, 2022). With steadily rising per capita CO<sub>2</sub> emissions – 0.232 tonnes per capita in 2019 – the sector has experienced a 214% increase compared with 1990 levels (Climate Watch, 2023). Though absolute levels are low compared with the global average of 1.07 tonnes per capita (2019), India's relative change is much higher than the world average of 23%. As such, the

transport sector is rapidly increasing in terms of its contribution to country emissions and will be a crucial sector for decarbonisation.

In the transport sector, the scope of this study is narrowed to electric vehicle (EV) measures for road transport journeys, as these present one of the greatest areas of opportunity for investment in the near term and to meet India's long-term low-carbon development strategic goals (MoEFCC, 2022b). India's transportation sector includes road, rail, aviation and maritime segments; however, road transport alone accounts for 92% of total transportation sector emissions (Kamboj et al., 2022). Low-carbon measures in rail are excluded here as India has nearly met its long-term goal of fully electrified passenger and freight rail: as of January 2024, 94% of the broad-gauge route of Indian railways has been electrified (Ministry of Railways, 2024). The aviation and maritime segments involve international movements and are thus outside of the scope of this study's specific focus on mobilising domestic capital for low-carbon investments in the short term.

Road transport is largely divided into three segments: personal and commercial vehicles, freight vehicles and public transportation. Personal and commercial vehicles include two-, three- and four-wheel vehicles for private or ride-hailing trips. Freight vehicles include light-, medium- and heavy-duty trucks (LDTs, MDTs and HDTs), mostly for commercial transport. Public road transportation comprises local and inter-city buses. In this study, low-carbon measures in the road segment are constrained to battery electric

vehicles (BEVs) and options for traditional internal combustion engine (ICE) vehicles.<sup>1</sup> Though hybrid, hydrogen fuel cell, liquefied natural gas (LNG), compressed natural gas (CNG) and biofuel vehicles are expected to contribute to India's low-carbon development (MoEFCC, 2022b), the cost-benefit analysis is limited to zero-emission BEVs, to provide insights on those that might be cost-effective in the near term and provide the most ambitious carbon emissions reductions compared with a business-as-usual (BAU) scenario.

## 2.2 Building

Housing is a critical sector for human well-being, and it will be increasingly important to provide citizens with cool, comfortable and safe housing in the face of increasingly frequent and severe climate hazards in India. Within the next two decades, India is set to more than double its building space (IEA, 2021). However, the sector already contributes around a third of the country's energy use (NIUA and RMI, 2022) and 6% of the country's energy-related emissions. After the transport sector, it is the fourth largest energy-related emitter (Climate Transparency, 2022). In 2019, the sector contributed 164 million tonnes of CO<sub>2</sub> emissions, with the majority coming from residential buildings (93 million tonnes) and the remainder (71 million tonnes) from commercial buildings.

Per capita emissions from India's building sector were almost four times lower than the G20 average in 2021. However, they increased by 5.7% between 2016 and 2021, (Climate Transparency, 2022) and are expected to increase further. As

<sup>1</sup> BEVs are the most cost-effective means to decarbonise passenger road transport and have already demonstrated lower cost of ownership of fossil fuel cars in leading EV markets like the EU and China. In addition, the purchase price of BEVs is expected to fall below that of an equivalent petrol or diesel car as early as 2027 in India (Lam and Mercure, 2022; EEIST, 2023; RMI, 2023). Maintenance costs for BEVs are based on point-charging models, as this is the current paradigm in the country; however, battery-swapping models and subscription services are a growing market with potential increased cost savings (Dash and Bandivadekar, 2021; Seetharaman et al., 2023).



the population rises and building space increases, it is expected that there will be a significant increase in energy demand with the uptake of clean cooking, cooling and other appliances (IEA, 2021). Therefore, as India proceeds to build new buildings, a timely transformation of the building sector using low-carbon measures can reduce energy consumption and emissions and put the sector on a path to low-carbon development.

In the building sector, the scope of this study focuses on both residential and commercial buildings. India's urban population is projected to increase from 470 million in 2019 to 740 million in 2040 (IEA, 2021). The building stock of commercial buildings is expected to increase from 1.7 billion m<sup>2</sup> in 2020 to 3.2 billion m<sup>2</sup> in 2037. For residential buildings, the building stock is expected to increase from 5.9 billion m<sup>2</sup> in 2020 to 15 billion m<sup>2</sup> in 2040 in urban areas and from 11.8 billion m<sup>2</sup> in 2020 to 21.4 billion m<sup>2</sup> in 2024 in rural areas (World Bank, 2022). Low-carbon measures in both residential and commercial buildings can reduce the projected growth in energy demand and contribute to emissions reduction. As a result, we focus on these two segments.

Mitigation measures in the residential and commercial building sector also provide significant opportunities for investment. For instance, as developers begin to employ green building certification schemes, the demand for green construction finance will increase (IFC, 2016). The green buildings market in India will have an estimated investment potential of approximately \$1.25 trillion and \$228 billion for residential and commercial buildings, respectively (World Bank, 2022). There are also opportunities for financial institutions to develop innovative financing schemes for renewable energy, to either support direct investments by households or businesses or provide loans to energy service providers,

as well as opportunities to provide consumer financing products for energy-efficient appliances (IFC, 2016).

## 2.3 Agriculture

The agriculture sector plays a critical role in India's development. It employs 42.3% of the workforce, which is the largest share for a single sector, and contributes 16.5% to GDP. The sector also employs the largest share of women workers (71%) in rural areas (Gulati and Juneja, 2022). Agriculture is also important for health and well-being in a country where the average household spends about 45% of its expenditure on food and 17% of the population were undernourished in 2021 (World Bank, 2024b). Thus, the sector contributes significantly to the livelihoods of people in India, especially given that 64% of the population in 2023 lived in rural areas, where agriculture continues to be a dominant activity and source of income (World Bank, 2024c).

While the agriculture sector contributes only 3% of the country's energy-related carbon emissions, it contributed 15% of the total sectoral GHG emissions in 2019 (Climate Transparency, 2022). The largest sources of the sector's GHG emissions consist of enteric fermentation, livestock manure, use of synthetic fertilisers and rice cultivation (Climate Transparency, 2022). Unlike other sectors, agriculture is the main source of methane (CH<sub>4</sub>) and nitrate oxide (N<sub>2</sub>O) emissions. The CH<sub>4</sub> emissions result from livestock rearing – enteric fermentation and manure management – and rice cultivation, whereas N<sub>2</sub>O emissions come from the application of fertilisers to agricultural soils (MoEFCC, 2022a). Given the importance of the sector to the Indian economy, a green transformation is crucial.



India's agriculture sector requires transformative changes through low-carbon pathways like reducing/stopping the burning of residues, management of soil nutrients, mitigating livestock emissions, low-energy-intensity irrigation and zero tillage. In this study, emissions from agriculture consist of emissions from both crop and animal production. Consequently, low-carbon measures considered in this sector are related to these two agricultural subsectors.

In the crop production process, emissions are released before planting, during growing and post-harvest. Measures to mitigate GHG emissions before planting include zero tillage. Techniques such as efficient nutrient management and low-energy irrigation are considered to reduce GHG emissions during growing. These measures are designed to minimise GHG emissions and optimise nutrient use. Of particular interest in India's case is rice cultivation, which is a major source of GHG emissions from agricultural crops. Rice cultivation releases about 71.4 million metric tonnes of carbon, representing 17.5% of total emissions from agriculture. Groundwater irrigation used in rice/paddy production releases 45.3–62.3 million metric tonnes of carbon (Rajan et al., 2020). Furthermore, low GHG-emitting measures relating to reducing residual burning post-harvest are considered. Agricultural crop residue-burning leads to the generation of GHGs like CO<sub>2</sub>, carbon monoxide, ammonia, nitrogen oxide and sulphur oxide (Chachei, 2024).

In animal production, low GHG-emitting measures related to changing the composition of livestock feed are considered. The majority of GHG emissions from livestock come from enteric

emissions, whose methane production can be reduced by altering the diets of livestock.

## 2.4 Gender equity and social inclusion

Social inequalities affect the uptake of and benefits from low-carbon measures and are thus important to consider alongside our economic analysis. Inclusion and exclusion are driven by social norms, which are based on factors such as sex, age, physical ability, caste, religion, and wealth or income. Intersecting social norms in turn shape and constrain individual and collective agency, including economic empowerment (Harper et al., 2020). Inequalities manifest in differences in labour force participation, health outcomes, education, asset ownership and responsibility for care work, which all shape an individual's ability to adopt or invest in proposed low-carbon measures.

Having waged employment with a regular income has direct impacts on the ability of an individual to uptake and use a low-carbon measure such as investing in a low carbon cooling system or an EV. But twice as many men as women participate in the Indian labour market (ILO, 2024).<sup>2</sup> This gap in labour force participation can be explained in part by a prevailing gender norm (60% of public opinion) that considers that 'when jobs are scarce, men should have more right to a job than women' (Haerpfer et al., 2022). It can also be explained by the prevalent norm that women take charge of most of the unpaid care work in a household. On average, Indian women spend almost 8 times as much time on unpaid care and domestic work as men – far higher than the global average of 3.2 times (MOSPI, 2020). Imbalances such as these limit time for women's income-earning

<sup>2</sup> 80.5% for men aged 15–64 while the equivalent figure for women was just 37.5% – a stark labour force participation gender gap of 43 percentage points.

activities and, in addition to lower wages, constrain subsequent investment opportunities.

Similarly, systemic inequalities manifest in unequal asset ownership for women, with more men than women owning property, as well as other forms of assets (Agarwal et al., 2020). Unequal access to education, where dropout rates are higher for girls than for boys (Ministry of Finance, 2023), directly affects future income potential. In addition, gender norms can have physical implications for women's health and safety, which again may preclude them from taking up economic opportunities and ultimately adopting and/or benefiting from low-carbon measures (Saikia et al., 2016; Marcus and Somji, 2024).

Other forms of social exclusion are also prevalent in the Indian context. Similar to gender norms and dependent on the region, caste norms can be powerful in shaping attitudes and behaviour that contribute to social and economic exclusion

(Sundaram and Tendulkar, 2003; Sengupta and Guchhait, 2021; Chatterjee et al., 2023). They limit individuals' ability to work or to play a part in a community and discriminate against so-called Scheduled Castes and Scheduled Tribes – groups that have historically formed the lower socioeconomic classes of Indian society (Agte and Bernhardt, 2023). Further, where gender intersects with these other forms of social exclusion, the relative disadvantage is often compounded. For instance, women from Scheduled Tribes are less likely than other women to have a bank account.

Altogether, these dynamics constrain women's and marginalised individuals' decision-making and economic agency, which in turn affects their ability to make investment decisions or benefit from low-carbon investments, even if these are more cost-effective. We further discuss such distributional effects for asset owners and users and potential implications for workers in Section 5.

### 3 Methodology

In this paper, we assess the scope of cost-effective climate mitigation measures that could be adopted and invested in at scale across India. To this end, we conduct a bottom-up assessment of the economic cost and climate benefits of a range of low-carbon measures and technologies to 2030. We calculate the differential cost of investing in a low-carbon measure compared with the current BAU measure in the transport, building and agriculture sectors and focus on the additional direct emissions produced by BAU measures compared with low-carbon measures. The cost-benefit analyses of each measure are then drawn together to provide evidence on the case for low-carbon investments in these sectors, which has the potential to help unlock and secure increased investment in these low-carbon measures at scale. In order to undertake this

analysis and produce compile league tables of the most cost- and carbon-saving potential measures, we undertake a series of steps.

#### 3.1 Identification and assessment of low-carbon measures

A longlist of low-carbon measures was compiled from the academic and grey literature. This was then cross-checked in key informant interviews (KIIs). Four KIIs were conducted for the transport sector, three for the agriculture sector and five for the building sector. Following these KIIs, a final short list of measures was created based on feasibility and data availability. Table 1 presents a list of all the measures considered; Appendix 1 presents a description of each measure.

**Table 1** List of low-carbon measures included in this study

Sector	Low Carbon Measures	BAU Measures
<b>Transport</b>	Light-duty trucks (LDTs) (<3.5 tonnes)	Diesel LDT
	3-wheeler battery electric vehicle (BEV)	Diesel 3-wheeler
	2-wheeler battery electric vehicle (BEV)	Petrol 2-wheeler
	4-wheeler battery electric vehicle (BEV)	Petrol 4-wheeler
	Medium-duty trucks (MDTs) (3.5–12 tonnes)	Diesel MDT
	Buses (9m, 12m, 13.5m lengths)	Diesel buses (9m, 12m, 13.5m lengths)
	Heavy-duty trucks (HDTs) (>12 tonnes)	Diesel HDTs
<b>Building</b>	Cool Roofs (Reflective Paint)	Demand for cooling energy
	Commercial Green Buildings	Traditional commercial buildings
	Residential Green Buildings	Traditional residential buildings
	LPG Cookstove	Fuel switching from biomass
	Commercial Solar Rooftop	Electricity sourced from fossil fuels
	Residential Solar Rooftop	Electricity sourced from fossil fuels

Sector	Low Carbon Measures	BAU Measures
Agriculture	Zero Till seed drill	Complete Flooding
	No Tiller planter	Conventional Tillage
	Cold storage – solar	Cold storage – subsidies coal generated electricity
	Solar pumps	Ground water pump – diesel & grid electricity
	Drip Irrigation – sugarcane	Full flooding in Sugarcane
	Drip Irrigation – vegetables	Convention flooding in vegetables
	Alternate wetting & drying in rice paddies	Complete Flooding
	Rotavator	Residual burning
	Paddy straw chopper	Residual burning
	Happy seeder	Residual burning
	Reaper binder	Residual burning
	Baler	Residual burning

Source: Authors

Some long-listed measures require further development before being brought to market, such as BEV options for people with physical disabilities, and may not be scalable in the near term to 2030; these were therefore not included in the shortlist (based on KIIs, 2024). Some measures, such as those related to cooling and appliances in the building sector, were not included in the study because interviewees indicated that they were common measures that were already highly deployed (KII 8, KII 9) and had become more affordable, with only small cost differences between the more efficient models (KII 8). Moreover, it was indicated that existing policies had already made it easy for consumers to choose the most energy- and emissions-efficient options (KII 8). Similarly, some measures with lower barriers to entry, such as lower capital costs for women on low incomes, were unable to be costed owing to a lack of data on utilisation, costs and deployment; many of these measures are still nascent and not commercially scalable in the near term, and thus

are out of the scope of this near-term study. For other excluded long-listed measures, there was a lack of available data on potential uptake, such as private school buses that could be electrified and district cooling for buildings.

Following the shortlisting, we collected data on capital costs and recurring costs, including maintenance and operating costs, in addition to data on emissions in CO<sub>2</sub> or CO<sub>2</sub>e where appropriate for one unit of each low-carbon measure and their BAU alternative. In some cases, we include the recurring economic savings associated with adopting the low-carbon measure. For example, in the building sector, adopting solar panels to replace electricity sourced from fossil fuel-based electricity grid results in savings on electricity bills. We then calculated the extra cost and emission savings associated with adopting the low-carbon measure instead of the BAU alternative. Appendix 1 provides data sources and assumptions detailed for each sector.

In terms of emissions savings considered, we included other GHGs (non-CO<sub>2</sub>) where appropriate and feasible. We considered the CO<sub>2</sub>e emissions saved compared just CO<sub>2</sub>, as the global warming potential of CH<sub>4</sub> and N<sub>2</sub>O are 28 and 265 times that of CO<sub>2</sub> over a 100-year time horizon (Myhre et al. 2013). Thus, even relatively small emissions levels of these GHGs should be considered. Where appropriate, prices have been adjusted to reflect subsidies in the transport and agriculture sector. These are further elaborated in Appendix 1. We then assessed the likely costs and carbon savings associated with adopting each measure (instead of the BAU alternative) over the seven-year period from 2023 to 2030 and additionally from 2023 until the likely end of the lifetime of each measure. The findings from the cost-benefit analysis allow us to develop league tables showing which measures are cost- and carbon-effective until 2030 and which across their lifetime.

## 3.2 Discounting

A single discount rate is used in the cost-benefit analysis to convert all costs and benefits that will occur and accrue in the future into present values. For the purpose of this study, a discount rate of 6.75% is used, in line with the Reserve Bank of India (RBI) bank rate (a nominal discount rate),<sup>3</sup> as of September 2023 (RBI, nd). The bank rate represents the minimum rate of interest charged on lending to domestic banks and is the most influential rate set by the RBI, affecting the total money supply in the Indian economy (Business Standard, nd). The lending interest rate in India (the interest rate for the short- and medium-term financing needs of the private sector) ranged from 8.3% to 9.5% over 2018 to 2021 (Keelery, 2024). India's long-term interest rate (government bonds

maturing in 10 years) is 7.2% as of July 2023 (CEIC, nd). Hence, our chosen discount rate, set to the RBI bank rate, is conservative.

The 2023 bank rate is similar to pre-pandemic rates over the five-year period between 2018 and 2023 (4.25% to 6.75%) (CEIC, nd). Setting the discount rate to the RBI's bank rate balances concerns over lower discount rates that are more relevant to environmental appraisals over longer time horizon (e.g. if choosing the real interest rate for government bonds) and the unrealistic spending associated with higher discount rates (e.g. if choosing the lending interest rate). Next, because our analysis is by 2030 – i.e. it has a seven-year return profile, which is a short- to medium-term horizon compared to cost-benefit analyses which span 10-years or even a generation (30 years) – we use a constant discount rate.

Finally, we do not discount the CO<sub>2</sub>e emissions that are physical units. The nature of GHG emissions means that the more emissions accumulate in our atmosphere, the greater impact they will have (IPCC, 2022). Applying a discount rate on emissions, which implies that future emissions are less harmful than present ones, is contradictory and underestimates their harmful cumulative impacts over time.

## 3.3 Deployment at scale and aggregation

Following the evaluation of the costs and benefits associated with adopting one unit of each low-carbon measure instead of the BAU alternative over the time periods, we assessed the potential scope for deploying each measure at scale across India. Realistic but ambitious rates of deployment

<sup>3</sup> Bank rate is a nominal interest rate (Bank of England, 2024), which means it does not take inflation into account.

were sourced from the literature and cross-checked with experts for their feasibility. The deployment rates take into account the lifetimes and replacement rates of existing measures, as well as rate of changes and growth in the relevant sectors. The potential deployment at scale of these measures depends on technical, behavioural and political feasibility. While technology may be available, the political economy around uptake and implementation is an important factor. Hence, there are uncertainties as to the scope of deployment of each of the measures, and the results given below are conservative estimates. Details on assumptions for deployment of each measure are listed in Appendix 1. Regardless, this allows us to understand the potential overall additional costs needed to roll out each low-carbon measure at scale instead of the BAU alternative, along with the associated emissions that could be saved across India until 2030.

### **3.4 Assumptions and limitations**

First, while we acknowledge the interdependence of economic sectors and the energy sector in

India's economy, and recognise that an ambitious decarbonisation of the power sector and grid would reduce its emission intensity (CEA, 2023), the analysis focuses only on private and direct (scope 1) costs and benefits within each of the sectors being investigated. Second, for the scope of this study, a number of parameters are considered constant, and we do not include the impact of changes in land-use planning (i.e. we do not consider changes in land-use for agriculture and zoning for buildings or parking management for transport).

We also acknowledge the gender, equity and social inclusion implications of each measure and recognise that not everyone can take up or directly benefit from all measures. All measures have co-costs and co-benefits, as well as distributional impacts, which are not quantified and integrated in the cost-benefit analysis but are considered qualitatively in Section 5. This is because data on the distribution of benefits is more qualitative, and links to wider public policy choices related to access, inclusion and awareness.

## 4 Assessment of economic and climate benefits

### 4.1 Cross-sectoral analysis

We identified a range of cost- and emissions-effective low-carbon measures available across the transport, building and agriculture sectors in India that could affect each sectors' potential growth in emissions. Table 2 provides an overview of the cross-sectoral results, highlights which of the measures are cost-effective and ranks each measure by its ratio of cost to climate benefit. The table also provides details on the cost and emissions savings that could be gained if each measure is deployed at scale across India.

If we consider all the measures across sectors, we find that 12 measures are cost- and emissions-effective over the period to 2030. This means that,

if they are adopted instead of the BAU alternative in the current time period, by 2030 the investment will generate both cost and emissions savings. We also determine which measures have the greatest cost savings to emissions savings ratios and find that three agriculture measures top the list as those measures with the greatest ratio of cost to climate benefits.

If all the cost-effective measures across all three sectors are deployed at scale, it could result in economic savings of INR 2.9 million crore and 1,062 million tonnes of avoided CO<sub>2</sub>e emissions. These emissions savings could make a significant contribution to supporting India's pledge to cut its emissions by 1 billion tonnes by 2030 (MoEA, 2021).

**Table 2** Potential economic savings and emissions reductions associated with selected low-carbon measures across the transport, building and agriculture sectors

Sector	Measure	Per Unit				At Scale		
		Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)	Total emission savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs by 2030 (crore INR)	Total economic costs by 2030 (million USD)
Agriculture	No Tiller planter	-59	0.13	-461	-5,530	3.34	-154,132	-18,665
Agriculture	Cold storage – solar	-13,396	176	-76	-913	0.07	-557	-67
Transport	LDTs/LDV (<3.5T)	-1,937	39.05	-50	-595	80.62	-399,901	-48,426
Transport	3-wheeler EV	-795	22.4	-35	-426	120.56	-427,877	-51,814
Agriculture	Solar pumps	-426	12.06	-35	-424	42.21	-149,273	-18,076
Transport	2-wheeler EV	-126	3.65	-35	-416	293.65	-1,017,027	-123,158
Transport	4-wheeler EV	-1,128	37.44	-30	-362	139.71	-420,911	-50,971
Transport	MDTs (3.5–12T)	-2,245	106.9	-21	-252	82.52	-173,292	-20,985

Sector	Measure	Per Unit				At Scale		
		Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)	Total emission savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs by 2030 (crore INR)	Total economic costs by 2030 (million USD)
Agriculture	Solar powered drip Irrigation – Sugarcane	-38	22.64	-2	-20	22.64	-3,848	-466
Agriculture	Solar powered drip Irrigation – Vegetables	-19	28.73	-1	-8	28.73	-1,857	-225
Building	Cool Roofs – Reflective Paint (m <sup>2</sup> )	-0.01	0.07	0	-1.441	245	-2,931	-335
Agriculture	Alternate Wetting & Drying	8	22.08	0	4	513.08	11,440	1,385
Agriculture	Rotavator	31	59.5	1	6	115.8	5,984	725
Agriculture	Paddy straw chopper	63	59.49	1	13	115.77	12,287	1,488
Buildings	Commercial Green Buildings (m <sup>2</sup> )	0.6	0.5	1	13	24.61	2,691	326
Agriculture	Happy seeder	76	59.55	1	15	115.9	14,727	1,783
Agriculture	Reaper binder	140	59.74	2	28	116.26	27,306	3,307
Building	Residential Green Buildings (m <sup>2</sup> )	0.48	0.13	4	44	17.18	6,316	765
Transport	Buses (9m, 12m, 13.5m)	2,227	344.92	6	77	380.67	245,797	29,765
Agriculture	Baler	713	59.33	12	144	115.46	138,706	16,797
Building	LPG Cookstoves (Fuel Switching – Biomass to LPG)	36	2.63	14	163	3.91	5,324	645
Transport	HDTs (>12T)	11,590	422.11	27	330	1,179.25	3,238,025	392,112
Building	Commercial Solar Rooftop (kW)	1.3	0.02	84	1,010	0.1	822	100
Building	Residential Solar Rooftop (kW)	7	0.02	433	5,193	0.11	4,849	587

Source: Authors (for data sources see Appendix 1)

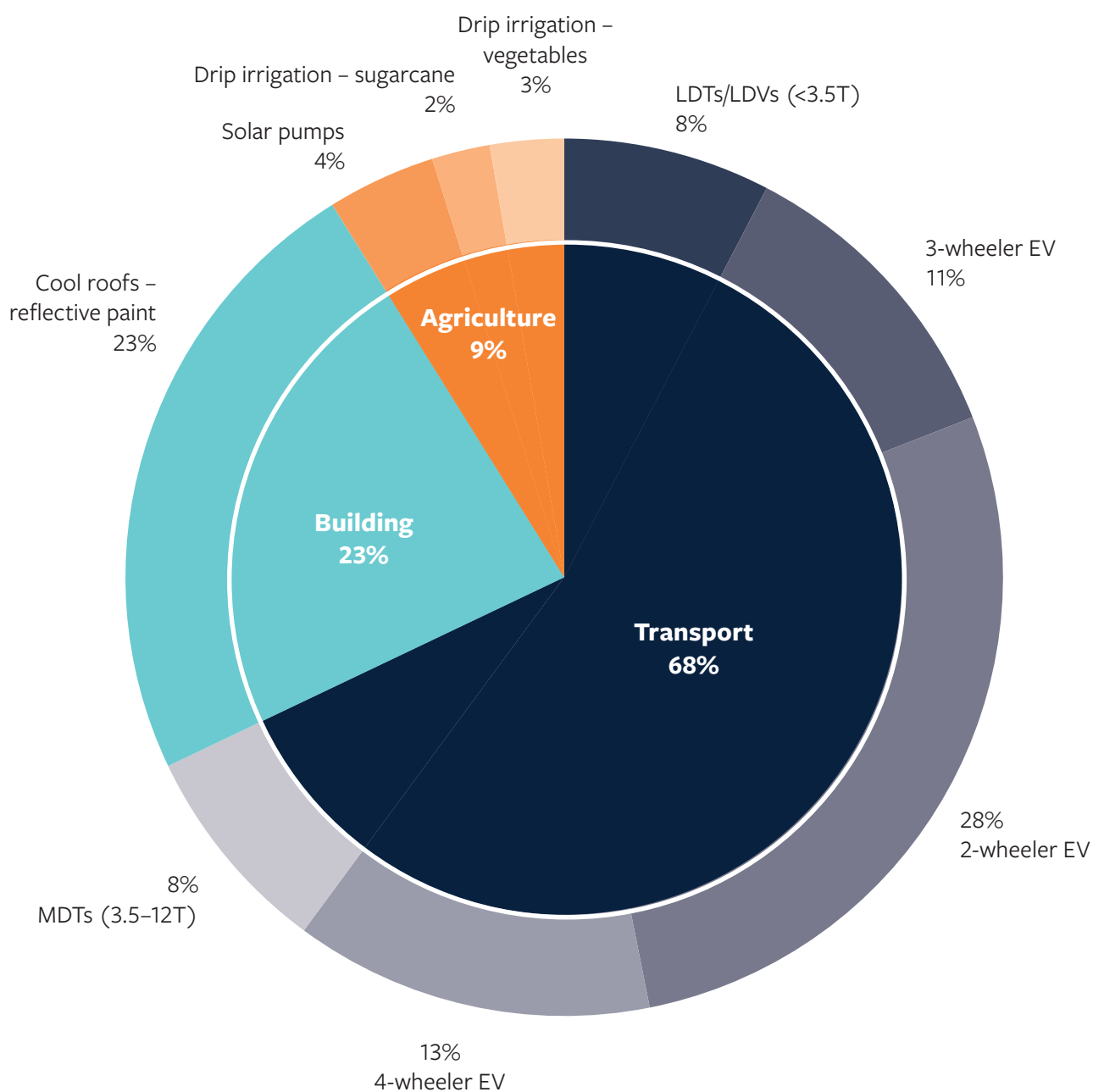
Note: Green corresponds to a measure that has a cost saving (negative value) and emissions saving compared with the BAU measure by 2030 and therefore has a greater cost to emissions benefit ratio (negative value); orange is for measures that over their lifetime rather than to 2030 have a cost saving (negative value) and emissions saving compared with the BAU measure; red corresponds to no economic savings over 2030 or lifetime (positive value). Exchange rate used for 2023, \$1 = INR 82.579 as per exchange-rates.org



When considering the total emissions reduction potential of the cost-effective measures, the largest share of emissions savings benefits can come from the transport sector, as Figure 1 highlights.

The transport sector accounts for 68% of the total emissions reduction potential of the cost-effective by 2030 measures, with two-wheeler EVs the greatest contributor.

**Figure 1** Share of emissions savings potential of measures that are cost-effective by 2030

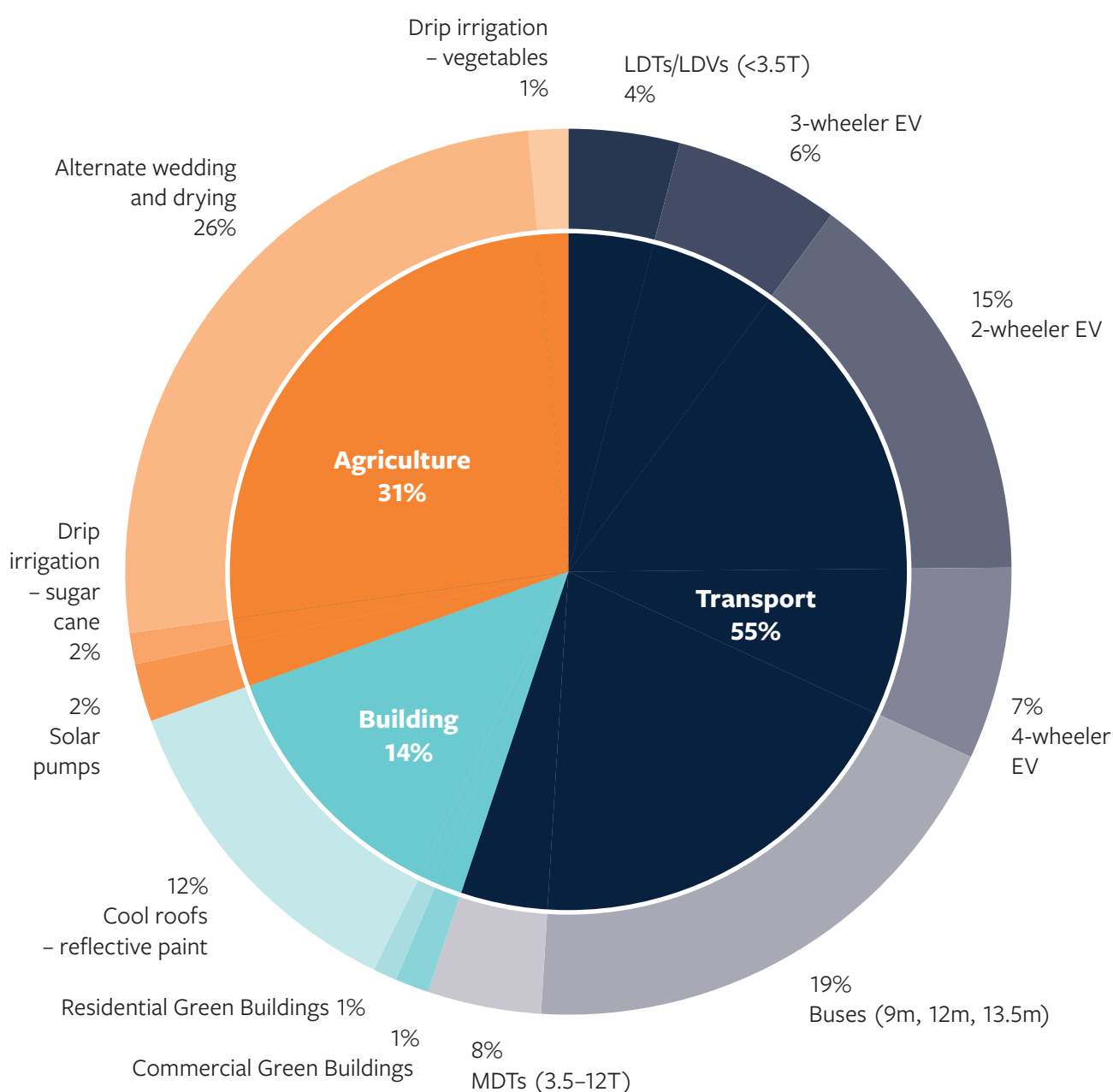


Source: Authors

When considering the measures that are not cost-effective by 2030 but become cost-effective over their lifetimes, they result in economic costs of only INR 271,000 crore. Therefore, if both the measures that are cost-effective by 2030 and the measures that are cost-effective over their lifetimes are deployed, economic savings are still positive at INR 2.7 million crore until 2030. If we

consider these additional measures, if deployed, they add an additional 936 million tonnes of emissions savings, which could bring total potential emissions savings to 1,998 million tonnes. Figure 2 shows where the potential emissions savings come from if all cost-effective measures are considered, including those that become cost-effective past 2030.

**Figure 2** Share of emissions savings potential of all cost-effective measures



Source: Authors

The transport sector continues to provide the most emissions reduction potential, with the greatest contribution from electric buses and two-wheeler EVs. However, given that they become cost-effective only over their lifetime and not by 2030, these require a more far-sighted outlook if being considered for investment.

The subsequent sectors provide details of each sector and discuss each measure. It is important to note that it is outside the scope of this study to consider potential emissions savings from increased decarbonisation of the country's power sector (corresponding to Scope 2 emissions in the case of our study). However, it is important to note that all measures presented would be even more carbon-effective if the emission intensity of India's electricity system reduced by 2070 as planned in India's long-term low carbon development strategy<sup>4</sup> (MoEFCC, 2022b).

## 4.2 Transport

Among the seven measures investigated in the transport sector, it was found that five of them were cost- and emissions-effective over the period to 2030. This means that, if they are adopted instead of the BAU alternative in the current time period, by 2030 the investment will generate cost and emissions savings. These measures include LDTs/LDV, which have the greatest cost to climate benefit ratio, where, for every 1 tonne of CO<sub>2</sub>e saved, INR 50'000 is also saved compared with the BAU alternative by 2030. This measure is followed by three-, two- and four-wheeler EVs and then MDTs, which also have positive cost and emissions savings. The fact that measures related to EVs come up as cost-effective showcases how innovative technology costs have come down in recent years.

**Table 3** Potential economic savings and emissions reductions associated with selected low-carbon measures in the Transport sector

Low-Carbon Measure	BAU Measure	Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)
LDTs/LDVs (<3.5T)	Diesel LDT	-1,937	39.05	-50	-595
3-wheeler EV	Diesel 3-wheeler	-795	22.4	-35	-426
2-wheeler EV	Petrol 2-wheeler	-126	3.65	-35	-416
4-wheeler EV	Petrol 4-wheeler	-1,128	37.44	-30	-362
MDTs (3.5-12T)	Diesel MDT	-2,245	106.9	-21	-252
Buses (9m, 12m, 13.5m)	Diesel buses (9m, 12m, 13.5m)	2,227	344.92	6	77
HDTs (>12T)	Diesel HDTs	11,590	422.11	27	330

Source, note and exchange rate: As for Table 2.

<sup>4</sup> Mostly through an increase in renewable energy with a target to achieve 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 (MOP, 2024).

Battery electric HDTs and buses are transport measures that are not yet cost-effective by 2030, as by 2030 adopting these measures will still be more costly compared with the BAU alternative. However, further analysis shows that buses become cost-effective over their lifetime. Batteries must be sufficiently large to manage the high daily operational distances for buses in cities and on inter-city routes and make up about 40% of the total electric bus cost (Kumar and Vijaykumar, 2022), which contributes to the higher marginal capital costs of adopting an EV compared with ICE alternatives. These barriers to adoption have already been studied in India: currently, battery electric trucks have higher upfront cost than ICE counterparts and are not widely manufactured or available, but operating cost savings are possible with decisive market creation and policy action (NITI Aayog and RMI, 2022).

Though decreasing battery prices will significantly contribute to the cost-effectiveness of battery electric trucks and buses, these nascent segments of the transport sector will require coordination across government, technology, industry and financial institutions to develop precise market

and policy intervention. Presently, capital costs and replacement costs for the large batteries required for these vehicles are significantly higher than for ICE vehicles, owing to limited manufacturing and availability (NITI Aayog and RMI 2022). The uptake of EVs will also require convenient charging infrastructure. The Bureau of Energy Efficiency expects 46,397 public charging stations to be built across 9 cities by 2030 (MOP, 2023). This will require significant capital expenditure (Bharadwaj, 2023).

However, large BEVs like trucks and buses provide potentially large opportunities for emissions savings in the transport sector and point to promising development in the future. In its most recent review of global EV battery trends, the International Energy Agency (IEA) observed that stabilising critical mineral prices led battery pack prices to fall almost 14% in 2023, with indicators that surplus battery material supplies will remain stable in the near term (IEA, 2024). An analysis of the opportunities to scale zero-emission battery electric trucks in India predicts that nearly 9 in 10 trucks sold in 2050 can feasibly be zero emission battery electric trucks, with significant emissions savings benefits (NITI Aayog and RMI, 2022).

**Table 4** Potential economic and emissions savings if transport measures are deployed at scale by 2030

Measure	Total Emission Savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs of adopting low carbon measure (crore INR)	Total economic costs of adopting low carbon measure (million USD)
LDTs/LDV (<3.5T)	80.62	-399,901	-48,426
3-wheeler EV	120.56	-427,877	-51,814
2-wheeler EV	293.65	-1,017,027	-123,158
4-wheeler EV	139.71	-420,911	-50,971
MDTs (3.5–12T)	82.52	-173,292	-20,985
Buses (9m, 12m, 13.5m)	380.67	245,797	29,765
HDTs (>12T)	1,179.25	3,238,025	392,112

Source, note and exchange rate: As for Table 2.

Given that Table 3 highlights the economic costs and emissions savings associated with adopting one unit of each measure, we consider the potential deployment of each measure at scale by 2030 (Table 4). In the transport sector, if deployed at scale, the cost-effective measures contribute to 717 million tonnes of CO<sub>2</sub>e reduction, with two-wheelers and four-wheelers providing the largest total emissions savings. Overall, this would also lead to total cost savings of INR 2588,281 crore compared with if the BAU measures were adopted.

### 4.3 Building

In the building sector, we find that only one measure is cost- and emissions-effective over the period to 2030. This measure is cool roofs using reflective paint, which is used to reduce demand for cooling systems. With this measure, if it is adopted in the current time period as a method to reduce rising cooling demand, by 2030 it will generate positive cost and emissions savings. However, it does so only on a small scale, which could be because we expect it only to substitute some demand for electrical cooling, and not to completely replace any cooling technologies. Therefore, it does not lead to any savings in capital costs, only an electricity bill reduction.

**Table 5** Potential economic savings and emissions reductions associated with selected low-carbon measures in the building sector

Low-Carbon Measure	BAU Measure	Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)
Cool Roofs – Reflective Paint (m <sup>2</sup> )	Demand for cooling energy	-0.01	0.07	0	-1.441
Commercial Green Buildings (m <sup>2</sup> )	Traditional commercial buildings	0.6	0.5	1	13
Residential Green Buildings (m <sup>2</sup> )	Traditional residential buildings	0.48	0.13	4	44
LPG Cookstoves	Fuel switching from biomass	36	2.63	14	163
Commercial Solar Rooftop (kW)	Electricity sourced from fossil fuels	1.3	0.02	84	1,010
Residential Solar Rooftop (kW)	Electricity sourced from fossil fuels	7	0.02	433	5,193

Source, note and exchange rate: As for Table 2.

While all of the measures have emissions reduction potential compared with their alternative, on further analysis most are not cost-effective by 2030. However, as we considered the cost savings gained from reduced electricity bills, we find that commercial and residential green buildings and solar panels will become cost-effective over their lifetimes. This finding is in line with the literature. For instance, research finds the costs of green buildings can be recovered through operational cost savings within a reasonable payback period (WorldGBC, 2021). These measures do provide significant CO<sub>2</sub>e emissions reduction by 2030, and over the next few decades economies of scale and technological improvements will further reduce the costs of solar photovoltaic (PV) (IRENA, 2019) and green buildings (WorldGBC, 2021). This suggests they are solutions still worth adopting in the near term.

The only building measure that does not become cheaper than the BAU alternative is LPG cookstoves, which represents a switch to LPG cooking from biomass, with a focus on informal settlements that still use polluting fuels only. This cost-ineffectiveness could be a result of the capital cost for the LPG installation and the high monthly expenditure on LPG refills, which contribute to the higher marginal costs compared with for other polluting fuels, which can be sourced for cheap

or sometimes free. According to the literature, these high lump sum costs have been cited as the main reasons for non-adoption of LPG among informal settlement households (Jha et al., 2021; Sreenivasan et al., 2023).

Although there are subsidies for LPG, some people do not have a bank account, which prevents them from gaining an LPG connection or a subsidy (Sreenivasan et al., 2023). Among India's slum households, where use of polluting fuels is common, there is also a lack of awareness of these subsidies (Jha et al., 2021), and in some rural areas and urban slums there is also a lack of awareness of the benefits of using LPG and perceptions around LPG being unsafe and leading to poor tasting food (Sreenivasan et al., 2023). Therefore, increasing awareness on LPG and the subsidy, and addressing the barriers to receiving the subsidy, may lead to increased uptake, allowing LPG to become even more cost-effective and leading to increased adoption. However, it has been found that, despite the subsidy, there is still an uneven increase in LPG usage: in 2022/23, one out of four beneficiaries of the subsidy scheme (Pradhan Mantri Ujjwala Yojana, PMUY) did not take any LPG cylinders or only took one, as the rise in cost of LPG cylinders still made it an unaffordable option, even for subsidised households (Porecha, 2023).

**Table 6** Potential economic and emissions savings if building measures are deployed at scale by 2030

Measure	Total Emission Savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs of adopting low carbon measure (crore INR)	Total economic costs of adopting low carbon measure (million USD)
Cool Roofs – Reflective Paint	245	-2,931	-335
Commercial Green Buildings	24.61	2,691	326
Residential Green Buildings	17.18	6,316	765
LPG Cookstoves (Fuel Switching –Biomass to LPG)	3.91	5,324	645
Commercial Solar Rooftop	0.1	822	100
Residential Solar Rooftop	0.11	4,849	587

Source, note and exchange rate: As for Table 2.

Cool roofs are considered to be a simple and cost-effective solution that can help offset rising cooling energy demand (NRDC, 2022). For example, Telangana adopted India's first state-wide cool roof policy with a vision to make the state heat-resistant through 'driving widespread adoption of cool roofs across the state, establishing a robust institutional framework for policy implementation, identifying financial mechanisms and conducting awareness campaigns and supporting workforce development and training in cool roof installation' (NRDC, 2023). There is great potential for this measure to be deployed at a large scale throughout other states in India, given the right policies. Using an ambitious but realistic rate of deployment, we estimate there is potential for cool roofs using reflective paint to contribute to 245 million tonnes of CO<sub>2</sub>e savings across India, as shown in Table 6, and INR 2,931 crore in cost savings.

## 4.4 Agriculture

We find that six of the agriculture measures are cost- and emissions-effective over the period to 2030. These measures include zero till seed drills, which have the greatest cost to climate benefit ratio, where for every tonne for CO<sub>2</sub>e saved, INR 673 is also saved compared with the BAU alternative by 2030. However, when considered in isolation, cold storage – solar provides the greatest cost savings, and solar-powered drip irrigation – vegetables provides the greatest emissions savings potential. The other that which provide cost and emissions savings include no tiller planters, solar pumps and solar-powered drip irrigation – sugarcane.

**Table 7** Potential economic savings and emissions reductions associated with selected low-carbon measures in the agriculture sector

Low-Carbon Measure	BAU Measure	Additional cost of adopting unit of low carbon measure (thousand INR)	Emissions savings from adopting unit of low carbon measure (tCO <sub>2</sub> e)	Cost to climate benefit ratio (thousand INR/ton CO <sub>2</sub> e)	Cost to climate benefit ratio (USD/ton CO <sub>2</sub> e)
Zero Till seed drill	Complete Flooding	-87	0.13	-673	-8,072
No Tiller planter	Conventional Tillage	-59	0.13	-461	-5,530
Cold storage-solar	Cold storage – subsidies coal generated electricity	-13,396	176	-76	-913
Solar pumps	Ground water pump – diesel & grid electricity	-426	12.06	-35	-424
Solar powered drip Irrigation – Sugarcane	Full flooding in Sugarcane	-38	22.64	-2	-20
Solar powered drip Irrigation – Vegetables	Convention flooding in vegetables	-19	28.73	-1	-8
Alternate Wetting & Drying	Complete Flooding	8	22.08	0	4
Rotavator	Residual burning	31	59.5	1	6
Paddy straw chopper	Residual burning	63	59.49	1	13
Happy seeder	Residual burning	76	59.55	1	15
Reaper binder	Residual burning	140	59.74	2	28
Baler	Residual burning	713	59.33	12	144

Source, note and exchange rate: As for Table 2.

The two measures, zero till seed drills and no tiller planters, relate to a change in agricultural practice and speak to the carbon sink capacity of soils. The alternative BAU measures (full tillage) to the

top two low-carbon measures have large GHG emissions owing to the high soil disturbance and degradation they cause.<sup>5</sup> By contrast, the low-carbon measures correspond to a less disruptive

<sup>5</sup> Full tillage mechanically modifies soil structure and over time causes soil degradation and erosion.



agricultural practice that limits carbon release from soils and maintains their capacity to store additional carbon. Measures related to solar-operated cold storage and solar-powered drip irrigation, which also top the list, showcase how innovative technology costs have come down in recent years.

Half of the agricultural measures are not cost-effective, although they are emissions effective. This is because of the zero cost of the BAU measure – for example burning of residues incurs no cost. However, such agricultural practices carry a large long-term cost as they damage the soil structure and ultimately can stop soils from acting as carbon sinks (Nazir et al., 2024). Therefore, implementation of the low-carbon measures could provide a range of additional benefits, including

benefits to human health – which are a win at a farmer level despite many farmers having limited understanding of the long-term impacts of these burning, hence requiring target awareness.

When considering deployment at scale, the proposed cost-effective measures in the agriculture sector can contribute to 100 million tonnes of CO<sub>2</sub>e savings, with the highest economic and emissions savings coming from solar pumps. Based on the BAU scenario estimated by the India Energy Policy Simulator, it is projected that between 2023 and 2030, emissions from agriculture will amount to 5,116 million tonnes of CO<sub>2</sub>e. Therefore, deploying the cost-effective measures at scale by 2030 could reduce the sector's emissions by 2%.

**Table 8** Potential economic and emissions savings if agriculture measures are deployed at scale by 2030

Measure	Total Emission Savings by 2030 (MtCO <sub>2</sub> e)	Total economic costs of adopting low carbon measure (crore INR)	Total economic costs of adopting low carbon measure (million USD)
Zero Till seed drill	3.34	-224,982	-27,244
No Tiller planter	3.34	-154,132	-18,665
Cold storage – solar	0.07	-557	-67
Solar pumps	42.21	-149,273	-18,076
Drip Irrigation – Sugarcane	22.64	-3,848	-466
Drip Irrigation – Vegetables	28.73	-1,857	-225
Alternate Wetting & Drying	513.08	11,440	1,385
Rotavator	115.8	5,984	725
Paddy straw chopper	115.77	12,287	1,488
Happy seeder	115.9	14,727	1,783
Reaper binder	116.26	27,306	3,307
Baler	115.46	138,706	16,797

Source, note and exchange rate: As for Table 2.

## 4.5 Social cost of carbon

There are substantial welfare implications of each avoided unit of emissions. Some measures may not be considered cost-effective per unit of emissions avoided but should be promoted as they contribute to substantial emissions savings and reduced pollution, which affects all individuals' health and livelihoods.

As a result, in addition to the evaluation of cost and emissions savings of each measure, we estimated the value of emissions saved in terms of avoided damage using the social cost of carbon (SCC). SCC is an estimate of the economic cost associated with climate change that results from an additional tonne of CO<sub>2</sub> released in the atmosphere. First calculated by Nordhaus (1992), it is a widely used metric to inform climate policy-making, notably in the US (which undertook a review of SCC under the Biden term), Germany, the UK, Canada and Mexico and in corporate sustainability accounting (UK Government, 2021; Rennert et al., 2022; EPA, 2023). Decision-makers can use SCC to frame the impacts (or benefits) of an intervention in monetary terms. This approach can be useful to appraise the benefits of the selected low-carbon measures through their associated, avoided cost of climate-related damage.

We use a country-level SCC for India at \$86<sup>6</sup> as per Ricke et al. (2018), rather than a global estimate that does not reflect heterogeneity of climate impacts and economic pathways across countries. This economic valuation of the marginal impact of climate change gives a monetary estimate to the emission saved from adopting low-carbon measures. It indicates the potential welfare gains by 2030 of investing now expressed in monetary terms rather than physical CO<sub>2</sub>e units.

Table 9 shows the cost of climate change impacts that deployment of each measure at scale can avoid. Since the measure with the largest emissions saving potential (as shown in Table 4) is HDTs, we find that the largest avoided cost of climate impacts comes from deploying this measure at scale. However, if we consider only the measures that are cost-effective, two-wheeler EVs deployed at scale across India can lead to approximately INR 2 trillion in avoided costs from the impacts of climate change. Importantly, the measure yielding the greatest emissions saving and avoided climate cost (i.e. HDTs in the transport sector) is not the most attractive measure in economic terms. However, given the large climate dividend of such a measure, it may be beneficial for the government in partnership with commercial banks to investigate policies and mechanisms that could increase financial support for the rollout of HDTs.

6 \$86 with a confidence interval (49–157) as calculated by Ricke et al. (2018) using a 2% discount rate and under their reference scenario.

**Table 9** Avoided cost of climate change – aggregate measures

Sector	Measure	Total Avoided Cost of Climate Change (INR billion)	Total Avoided Cost of Climate Change (USD billion)
Transport	HDTs (>12T)	8,375	100
Agriculture	Alternate Wetting & Drying	3,644	44
Transport	Buses (9m, 12m, 13.5m)	2,703	32
Transport	2-wheeler EV	2,085	25
Buildings	Cool Roofs - Reflective Paint	1,738	21
Transport	4-wheeler EV	992	12
Transport	3-wheeler EV	856	10
Agriculture	Reaper binder	826	10
Agriculture	Happy seeder	823	10
Agriculture	Rotavator	822	10
Agriculture	Paddy straw chopper	822	10
Agriculture	Baler	820	10
Transport	MDTs (3.5-12T)	586	7
Transport	LDTs/LDV (<3.5T)	573	7
Agriculture	Solar pumps	300	4
Agriculture	Drip Irrigation- vegetables	204	2
Buildings	Commercial Green Buildings	175	2
Agriculture	Drip Irrigation- sugarcane	161	2
Buildings	Residential Green Buildings	122	1
Buildings	LPG Cookstoves (Fuel Switching - Biomass to LPG)	28	0
Agriculture	Zero Till seed drill	24	0
Agriculture	No Tiller planter	24	0
Buildings	Residential Solar Rooftop	1	0
Buildings	Commercial Solar Rooftop	1	0
Agriculture	Cold storage- solar	1	0

Avoided costs also include reduced mortality and reduced ill health from pollution and adverse effects of heat, all which are directly affected by investment decisions in transport, building and agriculture. In India, these climate-

related health impacts disproportionately affect women on low incomes and increase where socioeconomic status, social and cultural norms limit women's coping capacities (WHO, 2014; Sorensen et al., 2018). Thus, the benefits

or adverse effects of investment decisions will affect women on low incomes and low-income households disproportionately owing to the resource constraints that limit those groups' adaptive capacity.

Last, but not captured in the SCC calculations, investment in low-carbon measures may also have a ripple effect on the economic structure and employment structure in India. The growth of industries in response to increased investment appetite in low-carbon measures across the three sectors could create employment opportunities,

including for women and marginalised groups. However, concerted efforts are likely to be required to ensure participation of women and marginalised groups in the formal job market, including through recruitment and re- or up-skilling training. This is especially the case in the transport and building sectors, where men fill most of the jobs (GE and Avtar, 2021; Habitat for Humanity India, 2023; Metro Rail News, 2023). For example, Convergence Energy Service Limited has targets on the proportion of women to be employed across its different departments and types of jobs (Shah and Sharma, 2024).

## 5 Inclusivity of low-carbon measures

In this section, we consider the potential gender, equity and social inclusion implications of the low-carbon measures. This is a qualitative discussion reflecting on the distributional effects of the low-carbon measures included in the cost-benefit analysis. It expands upon the near-term, economic perspective of the analysis to consider how investments provide welfare gains alongside environmental considerations from an equity and inclusion lens.

Because individuals may not own but still use or work along the value chain where the low-carbon measure is implemented, we consider the distributional effects of the low-carbon measures from two perspectives: that of owners and that of users.

### 5.1 Owners

First, low incomes and limited access to finance are two key barriers to investment and adoption of low-carbon measures. Low-income limits not only the private investment people can directly make in low-carbon measures but also how much people can borrow.

Determinants of women's access to finance in India are shaped at multiple levels, including gender constructs and intersecting religious and caste hierarchies (Govindapuram et al., 2023). A key factor for borrowing is the ability to produce an asset for collateral. But for many women, the unequal ownership of assets within a household limits their capacity to open a credit line and borrow for investment. In particular, women-headed households and those belonging to marginalised social classes are more likely to have limited assets and be on a low income, with

women from Scheduled Castes and Scheduled Tribes facing the greatest gender disparities in poverty (Lastrapes and Rajaram, 2016; Roy, 2023). As a result, for many women and individuals on a low income, some investments, even those with demonstrated economic and environmental benefits, can be impossible owing to lack of access to finance. Microfinance models such as credit cooperatives and digital financial services have had some success in mitigating this issue and could potentially be leveraged towards low-carbon investments. The Ministry of Social Justice and Empowerment has already launched credit-based schemes for people from Scheduled Castes, such as Aajeevika Micro-Finance Yojana, which provides loans of up to 90% at reasonable interest rates (NSFDC, 2024). Expanding such schemes to support the uptake of low-carbon alternatives could be explored.

A key underlying issue related to investment decisions in low-carbon measures is intra-household decision-making. Even if not formally the asset owner, a woman can be part of investment decision-making within the household. But decision-making ability is shaped by social norms, with the pervasive global norm being that the man holds ultimate power as the head of the household, particularly when it comes to major expenditure decisions (Muñoz Boudet et al., 2013). These gender differences are exacerbated in poor households (Muñoz Boudet et al., 2013.) and can influence decisions on how women spend their time and money, on household economic strategies and on the use of and investment in assets (Klein, 2017; Marcus and Somji, 2024). Hence, who formally controls the asset to be invested in (i.e. the building, the land, the vehicle) and resulting intra-household dynamics is likely to

play out in decisions to invest. Furthermore, these dynamics may differentiate how benefits from low-carbon investments are accrued, or how the operating cost savings from a low-carbon measure are redistributed within a household, or how these savings are used.

Far more men than women in India own assets – whether land, housing or vehicles. Nearly 70% of women in India do not own any land, either alone or jointly, while women from Scheduled Castes are even less likely than other women to own or buy land (UNFPA, 2023). As such, women are potentially unlikely to invest in measures presented for the agriculture sector. However, as they represent a large share of hired and family agricultural labour, women and marginalised groups will benefit from low-carbon investment decisions through reduced exposure to harmful practices such as pollution from burning residues or exposure to chemical agricultural inputs resulting from switching to low-carbon measures. Such benefits beyond ownership are significant across the measures in this analysis.

The same pattern is true for vehicles: women account for just 10–12% of new vehicle sales and mostly purchase on the second-hand market, which predominantly sells ICE vehicles (Mukherjee et al., 2020). Hence, in the near term, the vast majority of cars purchased by women will likely be second-hand ICE vehicles rather than BEVs. There are also gender disparities in the uptake of private vehicles more broadly, with women in paid work generally more reliant on public transportation and taxi services than on private two-wheelers or cars (Mahambare and Dhanaraj, 2022). Though the analysis demonstrates the financially attractive and cost-effective case for substitution of ICE vehicles with BEVs, these may not reflect the purchasing decisions many women and low-income households will face, and they will also

require expansion of the charging infrastructure. Overall, less roadside pollution from other low-carbon decisions will be broadly beneficial.

## 5.2 Users

As shown in Section 4.5, the welfare-enhancing benefits of low-carbon measures can be measured in monetary terms or can be costed. In addition to the avoided damage from climate change, measures have the potential to bring about even wider-ranging social benefits, especially for individuals who do not necessarily own the asset invested in or make the investment decision. A number of low-carbon measures can support greater social inclusion but require a more far-sighted outlook if we are to reap the benefits of investment. Here, we reflect on such measures and their associated social benefits.

Measures such as switching to LPG cookstoves or to EVs have implications in terms of avoided health impacts. Women and girls are more likely to suffer the negative effects associated with indoor pollution owing to cookstoves because of social norms related to care-taking responsibilities. It is estimated that household air pollution from solid fuels caused the death of over a million Indians in 2021, and over 33.5 million disability-adjusted life years, representing both years of life lost and years lived in poor health – and female household members are over 13 times more likely to be exposed (MOSPI, 2020; Health Effects Institute, 2024). Hence, while not economically cost effective over the lifetime, the switch from biomass to LPG cookstoves in informal settlements could bring large health benefits – notably to women and low-income households – by reducing the impacts of household air pollution (Jha et al., 2021). The government has been making efforts to improve access to clean cooking through initiatives such as the PMUY,

which has been used to provide subsidised LPG connections to millions of households, and through various other programmes of support (Patnaik, 2019). The PMUY has provided access to LPG to 95 million women facing poverty over a seven-year period (T20 India, 2023).

Regarding EVs, while not yet cost-effective in the near term, battery electric buses are cost-effective over their lifetime and provide large opportunities for emissions savings in the transport sector as well as large social benefits, in particular for women and individuals on a low income. Women are among the most frequent users of public transport across Indian cities, and usage is even higher among women from lower-income groups (Ollivier et al., 2022). Good transport systems are key to economic development, connecting people to jobs, schools, healthcare and one another, boosting productivity and well-being. Bad public transport systems impose costs on society through time wasted in congestion, money spent on fuel or fares and air pollution with its associated respiratory health problems (GIZ, 2022).

There is therefore a clear case for investment in public transport vehicles – in this case battery electric buses – to support combined environmental and social objectives.

Complementary measures to respond to women's transport needs could include women-only buses; zero tolerance of sexual harassment and strong enforcement mechanisms; reduced overcrowding and shorter waiting times through more regular and reliable services; safe, well-lit waiting areas and clean toilets at bus stations; and street lighting and real-time information to improve first and last mile connectivity (GIZ, 2022; Ollivier et al., 2022; Singh, 2024). Notably, Convergence Energy Services Limited has planned to take steps to make its e-bus depots more gender-responsive (Shah and Sharma, 2024). Some of these enabling factors hold true for other investments in the transport sector too – for example ensuring that charging points for EVs respond to women's needs regarding accessibility, safety and personal hygiene (KII 4).

## 6 Conclusion

Our research reveals that there are several economically attractive low-carbon solutions across India's transport, building and agriculture sector, which could both reduce emissions and generate cost savings if investors shift their capital towards these instead of the fossil fuel-based alternatives. Overall, if these cost-effective measures were deployed at scale across India, using ambitious but feasible rates of deployment for each measure, they could generate cost savings of INR 29 trillion, and could reduce emissions by 1.1 billion tonnes of CO<sub>2</sub>e by 2030, contributing to India's target to reduce its emissions by 1 billion tonnes of CO<sub>2</sub>e by 2030 (MoEA, 2021).

Moreover, we found additional low-carbon measures across the sectors could provide additional emissions reduction by 2030 but these become cost-effective only over their lifetimes and not by 2030. Therefore, investors may require a more far-sighted outlook as they consider these measures for investment. Additionally, with changing energy prices, public regulatory change and fast-paced innovation, some measures that are not cost-effective now may become so in the future. Furthermore, among all of the cost-effective measures, the transport sector measures provide the greatest share of emissions savings, suggesting that the sector may have the greatest potential for substantial change, if this is accompanied by a range of public policies, from curbing gender-based harassment and violence in public transport to financial products that cater to EVs.

Beyond cost savings, with additional support and awareness, low-carbon measures may generate social benefits and gender, equity and social inclusion opportunities. However, it is important to note that not every segment of Indian society

is in a position to invest in low-carbon measures. Households on a low income and many women within those households, in particular, may not have the finance or the collateral to access finance or even the agency to make investment decisions. Despite this, many women on a low income and marginalised groups would still benefit from some low-carbon measures as users, particularly in switching to LPG cookstoves and expanding low-carbon public transport, even if they are not the primary decision-maker on the decision to invest. In many cases, complementary measures, including public policies, are needed to address social norms that affect uptake and use.

In emerging market and developing economies such as India, a large proportion of the private investment needed to meet the country's climate targets is expected to come from private developers, consumers and financiers. Given that demand across these key sectors in India – transport, building and agriculture – is projected to rise over the next few decades, this provides an ideal opportunity to shift these private investors' capital towards low-carbon investments. However, one of the barriers to doing this has been a lack of well-identified opportunities.

The evidence generated in this report can therefore contribute to a business case for investment and support private investors' decisions to invest in the identified low-carbon opportunities. This investment can be in the form of a consumer's or a household's decision to purchase an EV instead of a diesel vehicle or a developer's decision to build a green building as opposed to a BAU building. However, given that some stakeholders may need financial support to undertake these investments, these findings



could also support financiers' decisions to offer innovative financing products for different green investments. Commercial banks in India could lend towards the measures identified, for example by offering low-interest loans to consumers wishing to invest. In doing so, if these decisions

and investments in low-carbon solutions are made at scale across India, this could put the country on a path to low-carbon development and could support India's pledge to cut its emissions by 1 billion tonnes by 2030 and reach its 2070 net zero emissions target (MoEA, 2021).

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# Appendix 1 Data sources and assumptions

## Transport

Low-carbon transport measures were selected through a review of the existing literature on low-carbon transitions for India's transport sector and KIIIs (Dash and Bandivadekar, 2021; Kamboj et al. 2022; NITI Aayog and RMI, 2022; Briceno-Garmendia et al., 2023; Roychoudhury et al. 2023). Through this process, the scope of the study was defined as the total cost and emissions savings of BEV alternatives compared with traditional ICE vehicles. Other measures, which may require public investment or are not financially feasible in the near term, such as parking demand management, cycling and pedestrian infrastructure and the production of new electric micro-buses or combi-taxis, are excluded.

Data on the specifications of base models for each ICE and BEV transport measure was collected.

Price information excludes subsidies, and ex-showroom prices are adjusted by 15% to account for existing subsidies. The second phase of Faster Adoption and Manufacturing of Electric Vehicles (FAME), a scheme to encourage the uptake of electric and hybrid vehicles, was in effect at the time of data collection. As of May 2023, FAME II incentives were INR 10,000 per kilowatt-hour with a cap of 15% on ex-showroom price; a price reduction of 15% is applied to the purchase price of all EVs in the study (see Satapathy, 2024). The first phase (FAME I) was introduced in April 2015 and the second phase (FAME II) was launched in April 2019 and extended in March 2022 to end in March 2024. A third phase (FAME III) is expected to be included in the next fiscal year's budget.

## Passenger transport segment

**Table 10** Assumptions and data sources

Low-carbon measure	BAU measure	Summary and key assumptions	Data sources/links
Electric 2-wheelers	ICE 2-wheelers	<p>This sub-segment is further categorised into two – electric scooters and electric bikes.</p> <p>We identified the top 7 players in electric scooters (Ola, Okinawa, Hero Electric, Ampere, Ather, TVS and Bajaj) representing a more than 80% market share in 2022. For each, the base model (or the one with smallest battery capacity) was selected for the cost-benefit analysis.</p> <p>For electric bikes, all those under INR 2.5 lakh was chosen (<a href="http://www.zigwheels.com/newbikes/electric-bikes">www.zigwheels.com/newbikes/electric-bikes</a> provided info on main players in the market).</p> <p>Vehicle prices and specifications for ICE 2-wheelers are based on the Honda Activa.</p>	<p>Market share of top EV 2-wheeler producers (Trade Brains).</p> <p>Data on electric scooter price, battery capacity, range and warranty from individual producers/OEMs (for e.g. Ola).</p> <p>Data on electric bike price, battery capacity, range and warranty from individual producers and/or automotive websites such as ZigWheels.</p> <p>For ICE 2-wheelers, data on purchase cost and fuel mileage collected from ZigWheels. Maintenance costs calculated using average of personal, last-mile delivery and ride-hailing 2-wheelers published in Dash and Bandivadekar (2021), converted to 2023 INR.</p>

Low-carbon measure	BAU measure	Summary and key assumptions	Data sources/links
Electric 3-wheelers	ICE 3-wheelers	<p>This sub-segment was further categorised into two – passenger and cargo. Within the passenger category are two types of vehicles – electric rickshaw and electric auto.</p> <p>Electric rickshaw is classified as low-speed vehicles, requiring a driving licence only in some states. They have a speed limit of 25 kmph and therefore are ideal for short-distance travel and last-mile connectivity.</p> <p>There are many players in this sub-segment. For our research, all the major OEMs in the market (such as Mahindra, Kinetic, Atul, Lohia and Terra) were selected.</p> <p>Electric auto is designed for longer commutes and autos are generally costlier than e-rickshaws owing to larger motors and batteries and compliance with stricter regulations (categorised as L5M vehicles under Central Motor Vehicles Rules 1989, following stricter regulations and requiring a driving licence). They have a speed limit of greater than 40 kph.</p> <p>For electric auto (both passenger and cargo), we selected primarily those OEMs that offer both electric and CNG/Petrol/Diesel/LPG variants (such as Mahindra, Piaggio and Bajaj) in their portfolio for a more comprehensive comparison. However, we also included OEMs that offer electric auto only, such as Kinetic Green, Terra Motors and Lohia.</p> <p>Vehicle price and specifications for ICE 3-wheelers are based on the Bajaj Re diesel.</p>	<p>Data on electric rickshaw price, battery capacity, range and warranty from individual OEMs and/or automotive websites such as Truck Junction and TrucksDekho.</p> <p>Data on electric autos (passenger and cargo) price, battery capacity, range and warranty from individual OEMs and/or automotive websites such as Truck Junction and TrucksDekho.</p> <p>Data on purchase cost and fuel mileage collected from Bajaj. Maintenance costs based on diesel 3-wheeler models, which are the most commonly used model by fuel type (Harikumar et al., 2022), and converted to 2023 INR.</p>
Electric 4-wheelers	ICE 4-wheelers	<p>In this sub-segment all electric 4-wheelers under the price tag of INR 30 lakh (ex-showroom) are included.</p> <p>The 4-wheeler segment includes ride-sharing and private segments. Average annual distance and maintenance costs were calculated as the average of ride-sharing and private segments, and used to calculate costs and emissions for all 4-wheelers in the study.</p> <p>Vehicle price and specifications for ICE 4-wheelers are based on the Maruti Swift.</p>	<p>Data on electric 4-wheelers price (ex-showroom), battery capacity, range and warranty from individual vehicle manufacturers/OEMs.</p> <p>Data on purchase cost and fuel mileage collected from CarDekho.</p>
Electric buses	ICE buses	<p>The top 5 e-bus OEMs in India – Tata Motors, Ashok Leyland (Switch Mobility), JBM Auto, Olectra Greentech and PMI Electro Mobility, which together hold a market share of 79% – were selected for the analysis. This list is based on data from Mordor Intelligence.</p> <p>Vehicle price and specifications for ICE buses are based on the Tata Starbus LP 810.</p>	<p>Data on electric buses price, battery capacity, range and warranty from individual OEMs and/or automotive websites such as Truck Junction and TrucksDekho.</p> <p>Data on purchase cost and fuel mileage collected from Trucksbuses.com. Maintenance costs based on costs for a 12 m diesel bus as shown in Vijakumar et al. (2022).</p>



## Freight transport segment

**Table 11** Assumptions and data per vehicles and sources

Low-carbon measure	BAU measure	Summary and key assumptions	Data sources/links
MDTs	ICE MDT	MDTs have a gross vehicle weight between 3.5 and 12 tonnes. Examples are larger pickup trucks, small tippers and delivery trucks.  For the sub-segment, major players mentioned on ElectricVehicles.in are considered.  Vehicle price and specifications for ICE MDTs are based on the Eicher Pro 2049.	MoRTH classification.  Data such as sticker price, battery capacity and range collected from Dash and Bandivadekar (2021).  Data on purchase cost and fuel mileage were collected from TrucksDekho. Maintenance costs based on the Diesel Ford Transit cargo van from Dash and Bandivadekar (2021), converted to 2023 INR.
LDTs/	ICE LDT	LDTs have a gross vehicle weight of up to 3.5 tonnes. Examples are pickup trucks, small vans and mini trucks.  Only 4 models from 3 OEMs (Tata, Switch and Mahindra) are available in the market. These were chosen for study.  Vehicle price and specifications for ICE LDTs are based on the Tata Ace Gold.	MoRTH classification.  The research relies on data from truck manufacturers (such as Tata Motors and M&M) and media reports (Ahluwalia, 2023).  Data on purchase cost and fuel mileage collected from TrucksDekho. Maintenance costs based on LDV vehicles shown in Burnham et al. (2021, p. 83), converted to 2023 INR.
HDTs	ICE HDT	HDTs have a gross vehicle weight exceeding 12 tonnes, e.g. large tippers, trailers and specialized trucks.  Currently, 2 OEMs (IPL Tech and Olectra) have launched HDTs in India. These were included in the study.  Vehicle price and specifications for ICE HDTs are based on the Eicher Pro 3019.	MoRTH classification.  Data such as sticker price, battery capacity and range collected from NITI Aayog and RMI (2022).  Data on purchase cost and fuel mileage from TrucksDekho. Maintenance costs based on representative diesel long-haul truck (Basma et al., 2023), converted to 2023 INR.

## Other assumptions

Capital and operating costs for a representative EV for each segment are calculated using the segment average of the subsidised base model sticker price (ex-showroom price) based on the FAME II price reduction of 15%, the cost of charging based on the average annual distance travelled by each vehicle segment, the average maintenance cost and the cost of battery replacement(s) over the study period and the vehicle's expected lifetime, which are based on the current kWh price and average number of years to complete 2,500 charging cycles.

Capital and operating costs for a representative ICE vehicle are calculated using base model sticker price, fuel mileage, annual cost of fuel and average annual maintenance costs based on average annual distance travelled by each vehicle segment and average maintenance cost over the study period and the vehicle's expected lifetime.

EV deployment by 2030 is based on the 2030 sales targets announced by the Indian government.<sup>7</sup> The aggregation for the transport sector represents the 2030 EV sales targets applied as a linear rate to the total expected new vehicle stock each year from 2023 to 2030 using BAU scenario data from

<sup>7</sup> The sales targets are based on an announcement by Union Minister Nitin Gadkari, available at Economic Times of India (2021).

the India Energy Policy Simulator, which amounts to 93,752,667 EVs of 223,787,179 new vehicles. This figure is a conservative estimate of the potential emissions savings for the sector, as the secondary vehicle market and emissions from existing vehicles are outside the scope of this study, which focuses on near-term investment opportunities for the Indian banking sector.

These calculations include adjustments for the following vehicle segments. The BAU vehicle

sales for the trucking segment is split into LDTs and HDTs. The HDT segment is split into MDTs and HDTs using the remaining non-LDT modal split between MDTs (22%) and HDTs (78%) in Niti Aayog and RMI India (2022). Thus, vehicle sales for MDTs are generated as 22% of projected HDT sales for each year in the BAU scenario, and vehicle sales for HDTs are generated as 78% of projected HDT sales for each year in the BAU scenario.

**Table 12** Other assumptions

Topic	Summary and key assumptions	Data sources/links
India's Grid Emission Factor	The GEF measures the amount of carbon emissions per unit of electricity generated. Data for India's most recently published GEF is taken from the CEA's CDM CO <sub>2</sub> Baseline Database.	<a href="#">CEA CDM CO<sub>2</sub> Baseline Database</a>
Battery lifetime and replacement	EV battery lifetimes range from 1,000 to 5,000 charging cycles. This study assumes a battery replacement after 2,500 cycles, which is applied to all BEV segments. The average annual distance and average battery capacity for each EV segment is used to calculate approximate years after purchase that would fulfil 2,500 charging cycles, which would then trigger a battery replacement.	Jones (2024)
Cost of battery	At the time of study, EV battery replacements are expected to cost 15,000-20,000 INR/kWh. The cost of each battery replacement for each EV segment is calculated using the average battery capacity of the segment multiplied by 15,000 INR.	Search (2023)
Electricity cost	Projection with a rate increase calculated as the average of the year-on-year percent change for years between 2017/18 through 2022/23, applied to the 2022/23 average consumer billing rate for EVs.	India Climate and Energy Dashboard
Cost of petrol and diesel	Projection with a rate increase calculated using the monthly average Price of Indian Basket of Crude Oil and Retail Selling Prices of Petrol and Diesel for January from 2018 to 2022, applied to January 2022 petrol and diesel prices, respectively.	Price of Indian Basket of Crude Oil and Retail Selling Prices of Petrol and Diesel for January from 2018 to 2022
Emissions factors for petrol and diesel	The CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O emissions factors for petrol and diesel are taken from SIMAP. These are converted to CO <sub>2</sub> e using each GHG's 20-year global warming potential as shown in the IPCC Sixth Assessment Report (AR6). The CO <sub>2</sub> e emissions factors for petrol and diesel are assumed to apply to all years of ICE vehicle use.	Natural Resources Canada (2014) Smith et al. (2021)
2030 sales targets	Set for 2-, 3- and 4-wheeler and bus vehicle segments based on an October 2019 announcement of 2030 targets by the Indian government.  Sales targets for BEV trucks (LDT, MDT and HDT) by 2030 are set using the High Electrification 2030 Scenario for medium- and heavy-duty zero-emission trucks. The assumed sales penetration for MDTs is applied to LDTs.	
2030 new vehicle stock	Total new vehicle stock is taken from the EPS India vehicle sales for cars and SUVs (4-wheeled), 2-wheeled vehicles, 3-wheeled vehicles, buses, light freight trucks (LDT) and heavy freight trucks. Heavy freight truck volumes are split into medium- (MDT) and heavy-duty (HDT) segments based on the 2022 modal split for freight movement in India (76% HDT, 21% MDT, 3% LDT; thus, the heavy-duty stock is assumed to comprise 78% HDTs and 22% MDTs).	Energy Policy Solutions Niti Aayog and RMI (2022)



## Building

Low-carbon building measures were selected through a review of the existing literature on low-carbon transitions for India's building sector and KIIs. Based on this, the study was limited to the following building sector mitigation measures: new

residential and commercial green buildings instead of new traditionally built buildings, residential and commercial rooftop solar PV (on-grid), fuel switching for cooking in informal settlements (biomass to LPG) and cool roofs (reflective paint) in informal settlements.

## Residential buildings

**Table 13** Assumptions and data sources

Low-carbon measures	BAU measures	Summary and key assumptions	Data sources/links
New residential green buildings	New traditional residential buildings	<p>We classify green buildings using IFC's EDGE green building certification system for emerging economies, which focuses on making buildings more resource efficient. Based on this, green buildings are those developed using the most cost-effective strategies to reach a minimum 20% reduction in energy and water use and embodied carbon in materials compared with standard local buildings. Strategies could include energy efficiency measures such as external shading devices and wall insulation, among others.</p> <p>Cost and emissions savings therefore refer to the economics costs and emissions saved from constructing each meter square of a green building compared with a traditional building.</p> <p>It was assumed that green buildings consume 25% less electricity and thus result in savings on electricity bills, and that green buildings cost 2% more to construct (IFC, 2023).</p> <p>To calculate potential deployment, it was assumed that green buildings as a share of total buildings were at 10% in 2023 and increase by an additional 2% every year. In 2017, India's residential building stock was 1,144 million m<sup>2</sup>, and was expected to grow to 3,090 million m<sup>2</sup> by 2035 (WRI India, 2023). A linear growth was assumed each year, and the percentage of green buildings was applied to determine the annual deployment of green buildings. This allowed us to calculate total deployment to 2030. This is a conservative estimate, as additional policy and financial drivers could increase the share of green buildings being built each year.</p>	<p>The research relies on project studies from IFC EDGE, which provide data on energy and carbon emissions savings from EDGE-certified green residential and commercial buildings in India. This data is used to estimate carbon savings from constructing green buildings compared with conventional buildings.</p> <p>It also uses data from IFC and MOSPI to determine average electricity consumption in green buildings compared with conventional buildings, and data from the India Climate &amp; Energy Dashboard to determine energy bill savings.</p> <p>We used data from Gleeds and IFC to determine the capital costs of constructing a green building compared to a conventional one.</p> <p>Data from WRI India (2023), which provides data on projected building stock, and EDGE Buildings was used to calculate the rate of deployment.</p>

Low-carbon measures	BAU measures	Summary and key assumptions	Data sources/links
Residential solar PV	Electricity sourced from fossil fuels	<p>We are considering solar rooftop PVs for residential buildings that have on-grid connectivity – i.e., the solar system is directly linked to the local electricity grid and this utility grid acts as a battery where the excess energy is fed.</p> <p>Since we are considering on-grid solar rooftop systems, there is no need for battery cells and battery storage.</p> <p>It is assumed that the solar PV of 1 kW needs to be serviced every 6 months.</p> <p>The rate of deployment is based on the assumption that a 4 GW target for rooftop solar will be met by 2030. Therefore, based on 2023 levels of installed capacity, we assume the potential increase in deployment needed to meet this target across residential and commercial solar PV.</p>	<p>The research relies on data from MNRE, which offers the benchmark cost for grid-connected solar rooftop systems for FY2021/22 for general category states. Since the cost does not include the GST rate, we add a 12% GST to the cost of the 1 kW solar panel. This is inclusive of total system cost and its installation, commissioning, transportation, insurance and 5-year annual/ comprehensive maintenance contract. This capital cost is used for both residential and commercial solar systems.</p> <p>Data on emissions saving (yearly CO<sub>2</sub> emissions avoided by PV) for India was sourced from IEA (2021), which states that 94.1 MT CO<sub>2</sub> is avoided yearly by using PV in India. We divided by total GW of installed capacity to calculate how much MT CO<sub>2</sub> per GW is avoided yearly.</p> <p>The rate of deployment of both residential and commercial solar panels, until December 2023, was calculated from the Bridge to India report (India Solar Rooftop Map).</p>
LPG cookstoves	Fuel switching from biomass in informal settlements	<p>We consider fuel switching from biomass to LPG in order to use LPG cookstoves. Savings and costs therefore refer to the emissions savings and economic costs associated with switching to LPG for cooking exclusively.</p> <p>We focus on informal settlements, as, according to Jha et al. (2021), there is a significant gap in the exclusive use of LPG between urban slum households and urban non-slum households. The share of urban slum households using exclusively polluting fuels is low, but we focus on this small subset as they are affected by indoor air pollution from the use of polluting fuels and are often ignored in public policy. Therefore, the analysis seeks to provide evidence on whether LPG cookstoves and switching from biomass to LPG is a cost- and emissions-effective measure that could be promoted among these stakeholders.</p> <p>We assume the capital costs for the low-carbon measure consist of the LPG connection cost and the cost of an LPG stove and safety hose, and the operating costs consist of the LPG fuel costs. The operating costs for the BAU measure consist of fuel costs.</p> <p>Although there are subsidies in place to encourage adoption of LPG in India, such as the PMUY, this subset has not switched. It may be the subsidy still does not reach all slum households and there is thus a need to expand it (Jha et al., 2021). Moreover, there are still some barriers to receiving the subsidy, such as lack of a bank account (Sreenivasan et al., 2023). Therefore, we do not consider the subsidy in the calculation of costs. However, we note that the subsidy will increase cost-effectiveness.</p> <p>To determine levels of potential deployment, we consider the number of slum households in India and the share of slum households that solely use polluting fuels. We assume LPG is extended and adopted by all slum households at a linear rate between 2023 and 2030 in order for India to achieve universal clean cooking by 2030. The deployment rate is ambitious but achievable subject to policy support that removes some of the barriers to adoption.</p>	<p>The research adapts data from Jha et al. (2021), for capital and operating costs.</p> <p>Data on emissions savings from fuel switching was sourced from T20 India, which gave the emissions reduction from one cylinder of LPG.</p> <p>Data on deployment was compiled and adapted using sources including the census data from the Office of the Registrar General and Census Commissioner, India, 2011 and Jha et al. (2021).</p>

Low-carbon measures	BAU measures	Summary and key assumptions	Data sources/links
Cool roofs (reflective paint)	Demand for cooling from alternative cooling methods	<p>We consider the use of reflective paint as an alternative to demand for cooling using electrical cooling devices.</p> <p>The savings refers to the emissions and costs savings that painting roofs with reflective paint produces, as it lowers (not completely replaces) usage of and demand for other cooling methods.</p> <p>The state of Telangana adopted India's first state-wide cool roof policy and aims to reach 300 km<sup>2</sup> of cool roofs by 2028. Given that cool roofs are one of the simplest and most cost-effective ways to help people cope with extreme heat (NRDC, 2023), in order to calculate the potential deployment by 2030 we make the broad assumption that at least half of the remaining states (particularly those with greater populations) adopt a cool roof policy and aim for an identical rate of deployment as Telangana by 2030. This is an ambitious rate of deployment that requires ambitious policy action. However, there are several other states and cities where cool roofs are already being considered and deployed, for example in Ahmedabad (Ground Report, 2023).</p>	<p>To calculate the electricity consumption saved for each square metre of reflective paint, and the rate of deployment, we rely on case studies and project proposals for cool roof projects in India. For instance, the Telangana Cool Roof Policy estimates that 300 km<sup>2</sup> of cool roofs could lead to 600 million kWh of electricity saved reduced over a period of 5 years (NRDC, 2023). The capital costs, which consist of the cost of the paint (approximately INR 5 per square foot), and the emissions were calculated based on Joshi (2022).</p>

## Commercial buildings

**Table 14** Assumptions and data sources

Low-carbon measures	BAU measures	Summary and key assumptions	Data sources/links
New commercial green buildings	New traditional commercial buildings	<p>We classify green buildings using IFC's EDGE green building certification system for emerging economies, which focuses on making buildings more resource efficient. Based on this, green buildings are those developed using the most cost-effective strategies to reach a minimum 20% reduction in energy and water use and embodied carbon in materials compared with standard local buildings. Strategies could include energy efficiency measures such as external shading devices and wall insulation, among others.</p> <p>Cost and emissions savings therefore refer to the economics costs and emissions saved from constructing each meter square of a green building compared with a traditional building.</p> <p>It was assumed that green buildings consume 25% less electricity and thus result in savings on electricity bills, and that green buildings cost 2% more to construct (IFC, 2023).</p> <p>To calculate potential deployment, it was assumed that green buildings as a share of total buildings were at 10% in 2023 and increase by an additional 2% every year. In 2017, India's commercial building stock was 1,160 million m<sup>2</sup>, and was expected to grow to 1,880 million m<sup>2</sup> by 2035 (WRI India, 2023). A linear growth was assumed each year, and the percentage of green buildings was applied to determine the annual deployment of green buildings. This allowed us to calculate total deployment to 2030. This is a conservative estimate, as additional policy and financial drivers could increase the share of green buildings being built each year.</p>	<p>The research relies on project studies from IFC EDGE, which provide data on energy and carbon emissions savings from EDGE-certified green residential and commercial buildings in India. This data is used to estimate carbon savings from constructing green buildings compared with conventional buildings.</p> <p>It also uses data from IFC and MOSPI to determine average electricity consumption in green buildings compared with conventional buildings, and data from the India Climate &amp; Energy Dashboard to determine energy bill savings.</p> <p>We used data from Gleeds and IFC to determine the capital costs of constructing a green building compared to a conventional one.</p> <p>Data from WRI India (2023), which provides data on projected building stock, and EDGE Buildings was used to calculate the rate of deployment.</p>

Low-carbon measures	BAU measures	Summary and key assumptions	Data sources/links
Commercial solar PV	Electricity sourced from fossil fuels	<p>We are considering solar rooftop PVs for commercial buildings that have on-grid connectivity – i.e., the solar system is directly linked to the local electricity grid and this utility grid acts as a battery where the excess energy is fed.</p> <p>Since we are considering on-grid solar rooftop systems, there is no need for battery cells and battery storage.</p> <p>It is assumed that the solar PV of 1 kW needs to be serviced every 6 months.</p> <p>The rate of deployment is based on the assumption that a 4 GW target for rooftop solar will be met by 2030. Therefore, based on 2023 levels of installed capacity, we assume the potential increase in deployment needed to meet this target across residential and commercial solar PV</p>	<p>The research relies on data from MNRE, which offers the benchmark cost for grid-connected solar rooftop systems for FY2021/22 for general category states.</p> <p>Data on emissions saving (yearly CO<sub>2</sub> emissions avoided by PV) for India was sourced from IEA (2021), which states that 94.1 MT CO<sub>2</sub> is avoided yearly by using PV in India. We divided by total GW of installed capacity to calculate each GW of installed capacity avoided how many MT CO<sub>2</sub> yearly.</p> <p>The rate of deployment of both residential and commercial solar panels, until December 2023, was calculated from the Bridge to India report (India Solar Rooftop Map)</p>

## Other assumptions

**Table 15** Assumptions and data sources

Topic	Summary and key assumptions	Data sources/links
Electricity cost	Projection with a rate increase calculated as the average of the year-on-year percent change for years between 2017/18 and 2022/23, applied to the 2022/23 average consumer billing rate for domestic and commercial buildings. We use an average for domestic and commercial buildings.	India Climate & Energy Dashboard

## Agriculture

The scope of this study is narrowed to low-carbon agriculture measures selected from the literature that offer the potential to move away from high carbon-emitting methods and techniques while also offering investment opportunities in the near term.

## Reducing or stopping residual burning

In-situ management of crop residue through mechanisation helps in reducing emissions and prevents loss of essential nutrients. Machinery like happy seeders, paddy straw choppers, zero till seed drills, reaper binders, balers and rotavators have been seen to be effective for in-situ crop residue management. For this study, we have selected these six machines from the literature that can be used as an alternative to burning of residues (MAFW, 2020).

**Table 16** Assumptions and data sources

Low-carbon measure	BAU measure	Summary and key assumptions	Data sources
Happy seeder	Residual burning	<p>This is a tractor-drawn machine that is no-burn and no-till. It cuts residue of previous crop and sows a new crop in its place. It is used primarily for sowing wheat without burning rice residue. The expected lifetime of this machine is 10 years.</p> <p>MAFW provides a list of machinery for residue management that includes a happy seeder of 9–12 tines.</p>	<p>This study relies on research that indicates that happy seeder technology offers a no-burn and cost-effective alternative to residue burning (CIMMYT, 2019).</p> <p>The cost can range from INR 150,000 to INR 175,000 (Indiamart). The average is used for our study.</p> <p>Data source for lifetime of the machine: Pati (2021).</p>
Rotavator	Residual burning	<p>This is a tractor-mounted machine with a lifetime of 10 years used for incorporating the residues into the soil, effective in managing residues along with weed control and nutrient absorption.</p> <p>The lifetime is assumed to be 10 years.</p>	<p>The capital cost of the machine is INR 80,000 (Ramulu et al., 2020).</p> <p>Data source for lifetime of the machine: Rana (2017).</p>
Zero till seed drill	Complete flooding	<p>This is a tractor-operated machine with 9–15 tines mostly used by farmers for decades. It is used for straw management and in rice-wheat cropping patterns. It is included in the list of crop residue management machinery provided by MAFW.</p> <p>The lifetime is assumed to be 10 years.</p>	<p>The capital cost of the machine is in the range of INR 35,000 to INR 80,000 (Indiamart). The average price is used for our study.</p>
Baler	Residual burning	<p>This is tractor-operated machine or in some cases an engine is incorporated within the baler. For this analysis, we study the tractor-operated baler. It is an ex-situ crop residue management machine that is either round or rectangular. These machines compress the residue into transportable bales.</p> <p>It is included in the list of crop residue management machinery provided by MAFW.</p> <p>The lifetime is assumed to be 10 years.</p>	<p>The cost of the baler machine is INR 1,450,000 (Chaba, 2023a).</p> <p>Data source for lifetime of the machine: Nadeem and Ghani (2018).</p>
Paddy straw chopper	Residual burning	<p>This is a tractor-mounted machine, typically 5–9 ft, used to cut, chop and spread straw in the field and then incorporate it in the soil in the harvested field. It is included in the list of crop residue management machinery provided by MAFW.</p> <p>The lifetime is assumed to be 10 years.</p>	<p>The capital cost of the machine is INR 161,000 (Ramulu et al., 2020).</p>
Reaper binder	Residual burning	<p>A reaper binder can be either self-propelled or tractor-mounted. A reaper cuts the crop and a binder puts the cut crop into bundles for easy transportation. It can also be used for effectively incorporating the residue into the soil. It is included in the list of crop residue management machinery provided by MAFW.</p> <p>The lifetime is assumed to be 10 years.</p>	<p>The cost of the machine can range from INR 120,000 to INR 600,000 (Exportersindia). The average price is used for our study.</p> <p>Data source for lifetime of the machine: Woyessa, Tafa and Tsegaye (2022).</p>

**Table 17** Assumptions and data sources

Component	Assumption	Source
Capital cost	The capital cost for all machinery does not include the cost of the tractor as we assume the farmer already owns the tractor for other farm operations. Hence, it includes only the cost of purchasing the machine after deducting the maximum permissible subsidy on the machine as given by the central government. The subsidy applies only to the capital cost and not to operational costs.	The details of the subsidy for each machine are given in the Central Scheme document on the Crop Residue Management (MAFW, 2021).
Operating cost	<p>It is assumed that the operating cost for all machines comprises the field preparation cost and is expressed as estimated average operational cost of machine (INR/ha) as given in the press release by MAFW on Promotion of Agricultural Mechanization for In-Situ Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi, a central government scheme for states.</p> <p>Since all machines are tractor-operated, fuel cost is added to the field preparation cost to get the total operating cost of each agricultural machine. Fuel cost is obtained by multiplying the fuel consumption (l/ha) of each machine by the diesel rate (INR/l).</p>	Average operational cost of machine is from MAFW (2021).
Emissions	<p>The emissions for each of these machines is taken from a 2022 study, Guru et al. 2022. The emissions are calculated by taking into account the fuel energy used by each of these machines and then converting it into its carbon equivalent (Carbon equivalent (kg CO<sub>2</sub>e ha<sup>-1</sup>) = Carbon equivalent of diesel (kg CO<sub>2</sub>e l<sup>-1</sup>) × Fuel consumption (l ha<sup>-1</sup>)). The power (fuel energy) required by the machine depends on its size and the time it takes to cover the field.</p> <p>The emissions from stubble burning in kg CO<sub>2</sub>e per hectare were calculate after dividing total emissions in kg CO<sub>2</sub> in the year 2020 by the agricultural land burned in hectares (2019–2020).</p> <p>To calculate emission savings, emissions from residual burning were subtracted from emissions released by each of the machines.</p>	Guru et al. (2022)
Cost-benefit analysis	<p><i>Emissions savings:</i> The emissions from stubble burning in kg CO<sub>2</sub>e per hectare were calculated after dividing total emissions in kg CO<sub>2</sub> in the year 2020 by the agricultural land burned in hectares (2019–2020).</p> <p>To calculate emission savings, emissions from residual burning were subtracted from emissions released by each of the machines.</p> <p><i>Cost savings:</i> To calculate the cost savings, cost of residual burning (INR/ha) was subtracted from the operational cost of each of these machines. We projected the diesel rate till 2030 based on year-on-year growth figures previously to calculate the operational cost component and add it to the field preparation cost.</p> <p>We have assumed that the amount of compensation a farmer demands to stop burning residue/stubble is the cost of residue burning that is incurred per hectare.</p> <p>After subtracting the two, we have discounted the marginal cost at the rate of 6% till 2030 (the period of our study) and the lifetime of the measure.</p> <p>For year 0 (2023), the capital cost and the operating cost of each machine is included in the calculations based on the assumption that the machine will be put to use in the same year it is purchased and hence fuel cost and field preparation cost will have to be incurred.</p>	Deshpande et al. (2023a) Chaba (2023b)
Deployment	In India, stubble burning incidents are dominant in the northwestern states, primarily Punjab, Haryana, Uttar Pradesh and the National Capital Region. State governments are active in setting annual targets to reduce or eliminate stubble burning incidents in their respective states. Further, there are 3 main ways to reduce stubble burning: in-situ crop management, ex-situ crop management and using bio decompressors; our study focuses only on in-situ crop management. The state government of Haryana has set targets to cut 43% of stubble burning by using in-situ crop management techniques while the central government has asked the state governments of Punjab, Haryana and Uttar Pradesh and the National Capital Territory of Delhi to strive to achieve zero stubble burning in the very near future. Therefore, for our study we assume that, pan-India as well, 43% of stubble burning can be eliminated using in-situ measures proposed by our study. In 2019, total agricultural land area burned was 4.5 million ha. If we assume that 43% of this land needs to be covered under crop residue management techniques, we can say that 43% of 4.5 million ha, or 1.9 million ha of land, needs to be covered under crop residue management machines till 2030.	

## Efficient nutrient management techniques

Carbon emissions in nutrient management techniques are a significant concern owing to their contribution to climate change. Traditional fertiliser production, of particularly nitrogen-based fertilisers, involves energy-intensive processes that release GHGs such as CO<sub>2</sub> and N<sub>2</sub>O. Biofertilisers, derived from organic sources such as beneficial microbes and compost, not only enhance soil fertility and structure but also contribute to carbon sequestration by promoting microbial activity and organic matter decomposition. Mulching techniques, which involve covering soil with organic materials like crop residues or compost, not only conserve soil moisture and suppress weeds but also enhance soil carbon content through the gradual decomposition of mulch materials. Incorporating farmyard manure into agricultural systems recycles organic nutrients, reducing reliance on

synthetic fertilisers and their associated carbon footprint. Moreover, utilising high-protein feeds in livestock farming can improve feed efficiency, reducing methane emissions per unit of meat or dairy produced and contributing to overall carbon mitigation efforts within the agriculture sector. Implementing these low-carbon efficient nutrient management techniques not only fosters sustainable agricultural practices but also plays a crucial role in mitigating climate change impacts.

Table 18 provides the summary, key assumptions and data sources for each of the five sub-measures of nutrient management techniques:

- **Capital cost** will include training, raising awareness that other fertilisers could be used rather than chemical ones. This can be assumed to be or already in the budget of agricultural extension offices.
- **Recurring cost** is the cost of buying the low-carbon fertiliser.

**Table 18** Assumptions and data sources

Low-carbon measure	BAU measure	Summary and key assumptions	Data sources/links
Slow-release nitrogen fertilisers		<p>Slow-release fertilisers are designed to provide a steady supply of nutrients to plants over an extended period. Unlike traditional fertilisers, which offer an immediate nutrient boost, slow-release formulations are engineered to release nutrients gradually.</p> <p>Slow-release nitrogen fertiliser is captured under the fertiliser direct benefit transfer system, which provides 100% subsidy on various fertiliser grades to fertiliser companies on the basis of actual sales made by retailers to beneficiaries.</p>	<p>Price data from Indiamart  <a href="http://www.eagri.org/eagri50/SSAC222/lec08.pdf">www.eagri.org/eagri50/SSAC222/lec08.pdf</a></p> <p>Ministry of Chemicals and Fertilizers (2022)</p>
Biofertilisers		<p>‘Centre will give 50% subsidy – ₹1,500 crore to the State for promoting the use of alternative fertilizer and other development works’ – we assume the same across India over the analysis timeframe.</p> <p>Biofertilisers can be used on a wide range of crops, but more frequently are used on legumes, cereals, oilseeds, fodder and root crops.</p>	<p>Price data from Indiamart</p> <p>The Hindu (2023)</p>
Farmyard manure		<p>Farmyard manure is prepared basically using cow dung, cow urine, waste straw and other dairy waste.</p> <p>We assume a 50% subsidy, as above.</p> <p>Vegetable crops like potato, tomato, sweet potato, carrot, radish, onion etc. respond well to farmyard manure.</p>	<p>Price data from Indiamart</p> <p>Tnau Agritech Portal</p>



Low-carbon measure	BAU measure	Summary and key assumptions	Data sources/links
Mulching technique/sheets		<p>Mulching is the process of covering bare garden soil with a porous material to improve the condition of the soil underneath.</p> <p>We assume a 50% subsidy, as above.</p> <p>A different thickness of mulching sheets is used for different crops. E.g. for vegetables, 15–30 microns is used; for orchids, film thickness ranges from 100 microns to 150 microns. More thickness is more durability.</p> <p>Mulching is carried out in rainfed areas to conserve soil moisture and prevent land degradation. To develop the rainfed area in India, the government has launched various initiatives, such as the Rainfed Area Development Programme (RADP) and the National Mission on Natural Farming. Under RADP, the government provides cost assistance to farmers to promote mulching, to improve water use and soil moisture. Given its multiple benefits, which are highly documented, and the government's focus on improving soil fertility, this will lead to a substantial increase in the adoption of mulching techniques in the coming years (CEEW, 2021). Out of the 71.4 million ha of rainfed area in India (51% of the total net sown area), as of 2021 only 20 million ha is being covered with mulching. Additionally, the Indian government set a target in 2019 to restore 26 million ha of land and achieve land degradation neutrality status by 2030. Given these factors and the lack of any government targets for mulching technique adoption, our study assumes a doubling of the area under mulching by 2030 in India.</p> <p>The mulching paper-laying machine is operated by tractor, hence the operating cost – the cost of the fuel – is included as a recurring cost.</p>	<p>Price data from Indiamart</p> <p>CEEW (2021)</p> <p>RADP Operational Guidelines</p>
Improved cattle feed		<p>Since enteric fermentation is the largest source of emissions from livestock, it is essential to shift to alternate feed options that lower CH<sub>4</sub> emissions from the sector. For the cost of improved cattle feed, we average across 5 feed types that are low methane-emitting: sorghum, maize silage, alfalfa hay, rapeseed meal and soybean cake.</p> <p>The cost of the BAU measure is averaged across 3 high methane-emitting feeds: soybean meal, which is high in protein but also causes high methane emissions and is different from soybean cake, paddy straw bales and grass silages. These three feeds are most commonly fed to livestock in India.</p> <p>To calculate the emissions reduction from switching to improved cattle feed from traditional cattle feed, we used the CO<sub>2</sub> equivalent emissions reduction figures from Project Drawdown's global study. The figures obtained were reduced to India by taking into account the size of the Indian animal feed market (2.4% of the global feed market). The figure was then divided by the number of cattle in India in 2019 to obtain 'kg CO<sub>2</sub>e emissions avoided per head of cattle in India by using improved cattle feed.'</p> <p>For the adoption rates of improved cattle feed, since there is a lack of data, we have assumed the market size of animal feed as a proxy for improved cattle feed in India on the presumption that all market-based feed is improved feed. Feeds are 'improved' from the traditionally based feeding system. In India, the predominant system is traditional feeding and cattle management practices. Traditional livestock production systems consist of grassland-based systems (traditional pastoral and agropastoral systems) and mixed or integrated farming systems (free range). Hence, the current and projected market size of animal feed in India is used for our analysis.</p> <p>We assume a 50% subsidy, as above.</p>	<p>Price data from Indiamart</p> <p>Souto et al (2022)</p> <p>Project Drawdown</p> <p>MAFW (2022)</p>



## Reducing emissions from crop production (irrigation and water management techniques)

Techniques provided in Table 19 were selected with the assumption that they provide significant options in reducing GHG emissions from crop

production while also maintaining the yield. Drip irrigation contributes to lower emissions as it has low water usage: less water being pumped in the field results in using less diesel pumping; it reduces N<sub>2</sub>O release from the soil, which is common when using flooding techniques; it maintains soil structure, limiting methane production.

**Table 19** Assumptions and data sources

Low-carbon measure	BAU measure	Assumptions	Data sources/links
Irrigation	Solar pump	Groundwater pump: diesel and grid electricity	
		A 3HP solar pump can irrigate a hectare. For this measure, we include capital cost with 60% subsidy. No fuel cost is used for solar pumping. We have assumed 1,000 annual working hours for a solar pump set. The maintenance cost of a PV panel is assumed to be 0.5% of the total capital cost per year. Operating a solar pump is assumed to be environmentally sustainable, emitting zero CO <sub>2</sub> . Solar pumps are assumed to operate for 12 years.	Goel et al. (2021) Goel and Sharma (2020) Rajan et al. (2020) Shim (2017) Shah (2021)
		The solar pumps are assumed to replace both electric pumps (from a grid largely supported by coal) and diesel pumps. For all the measures, solar, electric and diesel, we consider their usage under the conventional flood irrigation system. Emissions saved from operating solar pumps are equivalent to emissions from both electricity and diesel pumps if a complete shift to solar pumps is achieved. For this measure, the year 0 cost includes only capital cost. Year 1 costs include only maintenance since there is no cost of electricity or fuel. We do not include the DC pump motor replacement cost, assumed for after 10 years, costing INR 40,000, as this will be close to the lifetime of the pump, anyway. The Government of India aims to install 2 million new pumps and solarise 1.5 million existing pumps (previously diesel or electric). That is a total of 3.5 million solar pumps targeted by 2030. We use this number of pumps as the plausible rate of deployment and calculate the total carbon savings and economic costs.	
Drip irrigation – sugarcane	Full flooding in sugarcane	In this measure, we use capital cost with 40% subsidy. The subsidy applies to the one-off capital cost only. Operational costs do not include subsidies. We use an average cost per acre from a given range of INR 45,000–60,000/acre in the literature. We convert acres to hectares using a conversion of 1 ha = 2.47 acres. Maintenance cost is provided in US dollars (with an exchange rate 1\$=60INR) in the study we found. We calculate an average from different types of drip irrigation to obtain an average maintenance cost for drip irrigation in sugarcane farming assumed to be per year. We assume electric-powered drip irrigation as is commonly used (about 20 million irrigation pumps are electric pumps). A national average price of electricity in agriculture is assumed. Solar electricity can also be used for this type of irrigation. We assume the drip irrigation setup life span of 7 years. CO <sub>2</sub> emissions from drip irrigation are provided in tonnes and we convert them to kg (using 1 tonne = 1,000 kg).	Agri Farming Surendran et al. (2016) Jain et al. (2020) Haq (2023) Kumar et al. (2023)
		The alternative measure that this measure replaces is full flooding irrigation – the most common method of irrigation used in India. We only include capital cost and cost of electricity in the year 0 costs. This is considering that electricity will be used in the same year of investment to operationalise the system. Drip irrigation is part of the micro irrigation scheme the government has put in place. The government targets 1 million ha to be under micro irrigation.	Signup Trending Nature Narayanamoorthy (2022) Swarajya (2020)
Drip irrigation – vegetables	Convention flooding in vegetables	Similar assumptions as above in sugarcane.	

Low-carbon measure	BAU measure	Assumptions	Data sources/links	
Tillage	No tiller planter	Conventional tillage	We use capital cost with 50% subsidy. A no tiller planter is usually mounted on a tractor. The operating costs are assumed to relate to the operating cost of the tractor. Since different tractors have different operating costs, we assume an average operating cost of a standard tractor. For comparison, we assume conventional tillage – where soil is inverted and exposed – as the counterfactual. Emissions saved using a no till planter in the no till method relate to soil structure stability, water retention and saving, and carbon sequestration. These are not saved under conventional tillage. In addition, we assume the tractor uses 5.6 litres of diesel a day to till 1 ha. But we assume that the tactors tills for 2 months in a year to get a yearly operating cost. We use the yearly average price of diesel as provided by the government document to calculate the total annual cost of fuel consumption. For the year 0 cost, we include capital cost and cost of fuel to operate tractor. We do not include the capital cost of a tractor itself as we assume this is exogenous. We assume a lifetime of 7 years for the tillage blades. No till or zero tillage are part of conservation agriculture. Currently, about 1.5 million ha of land in India is under conservation agriculture. The government set a target to reduce land degradation on 26 million ha of land by 2030 through different land and soil management techniques. No or zero tillage system will play a significant role in this by 2026. At the moment, zero tillage is already being practised in 0.8 million ha of land in India. We assume this will be as part of conservation agriculture.	Raju et al. (2012) Guru et al. (2022) Desphande et al. (2024) Aryal et al. (2014) Jat et al. (2020) Bhan and Behera (2014) Desai (2023) CGIAR (2022)
	Zero till seed drill	Complete flooding	Similar assumptions as above in no till planter.	
Management	Alternate wetting and drying	Complete flooding	The capital cost of AWD can be as low as zero when locally sourced materials such as bamboo are used. However, in this case we assume a market price of INR 8,000 for 80 <i>pani pani</i> pipes (15 cm by 30 cm) required for 1 ha. No subsidy is provided under this technique, and none is assumed in the near future. No human labour costs and wages are assumed but we acknowledge this may understate the actual costs considering the opportunity cost of time for farmers.  This measure replaces complete flooding in paddy rice farms.  Since we assume no operation cost, the only cost under this measure is the initial cost of materials. The lifetime of this measure is dependent on the material of pipes; it can last for over 20 years with easy-to-make replacements.  The major emissions from paddy rice farming are a combination of CH <sub>4</sub> and N <sub>2</sub> O. In this analysis, we include only emissions from CH <sub>4</sub> . AWD is a low-intensity emission measure only when CH <sub>4</sub> is considered. Literature suggests AWD tends to intensify N <sub>2</sub> O concentration. 65% of the area under rice production in India is facing extreme levels of water scarcity. About 22 million ha are under irrigated rice ecosystems, which is about 49.5% of the total rice area in the country. AWD can be adopted for the 65% of 22 million ha = 14.3 million ha facing water shortage given that yield is not affected when using AWD compared with full flooding.	Indiamart  Oo et al. (2020) Richards and Sander (2014) Gupta et al. (2021) Velchala (2021) Mahajan et al. (2017) Mote et al. (2023)
Storage	Cold storage – solar	Cold storage – subsidies in coal-generated electricity	We assume 10 tonne solar-powered cold storage using capital cost subsidised at 60%. No electricity cost are assumed for solar-powered cold storage, which is assumed to have a life span of 10 years. We assume no emissions from this measure. We understand there are other emissions from the cold storage itself, such as chlorofluorocarbons, hydrofluorocarbons and methane. But these are gasses that will emanate from operating the cold storage facility whether solar-powered or electric-powered. As such, they cancel out with similar gasses from alternative measure. CO <sub>2</sub> emissions for alternate measure of electric-powered cold storage are provided in MtCO <sub>2</sub> e and are converted to kg CO <sub>2</sub> e for uniformity. A study conducted by the National Bank for Agriculture and Rural Development estimates that India needs about 416 cold storage facilities for its fruit and vegetables (Tuwari, et al 2022).	Mishra et al. (2020) Global Methane Initiative (2024) Carrier (2016) Tiwari et al. (2022)

# Appendix 2      List of key informant interviews

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Name	Sector of expertise	Description of key informant
KII 1	Transport	Transport experts at Indian policy research institute
KII 2	Transport	Energy experts at international energy research institute
KII 3	Transport	Urban transport experts affiliated with nonprofit organisation working on Indian energy and transport issues
KII 4	Transport	Sustainable finance and transport experts at development institution
KII 5	Agriculture	Sustainable food systems experts at Indian policy research institute
KII 6	Agriculture	Climate resilience experts at Indian sustainable development nonprofit organisation
KII 7	Agriculture	Agrifood experts at agricultural science nonprofit organisation
KII 8	Building	Green buildings expert in Indian industry
KII 9	Building	Green buildings expert in Indian industry
KII 10	Building	Urban buildings experts at development institution