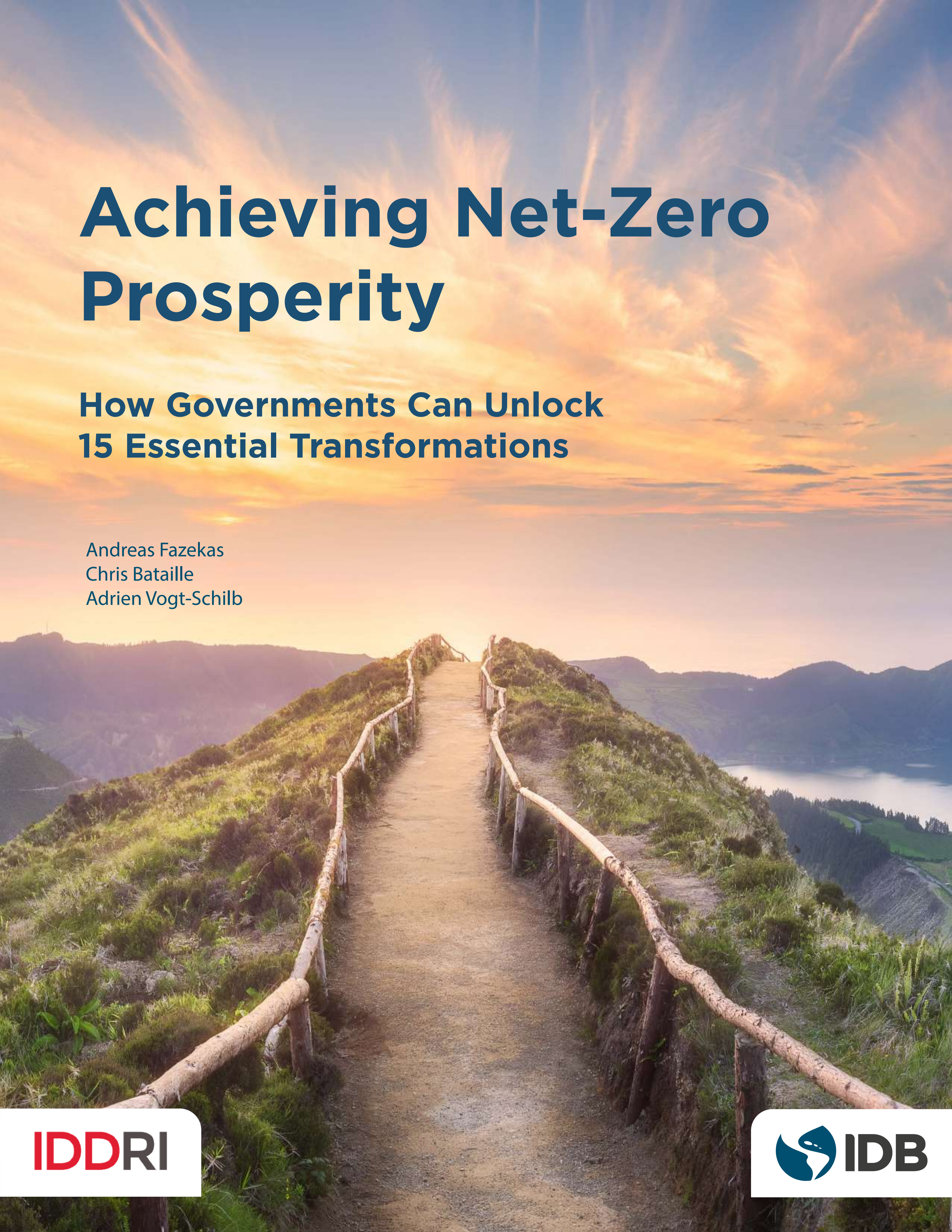

Achieving Net-Zero Prosperity

How Governments Can Unlock 15 Essential Transformations

Andreas Fazekas
Chris Bataille
Adrien Vogt-Schilb

IDDRI

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Foreword

The climate crisis is unfolding before us. The impacts have started to materialize, and they are affecting some of the most vulnerable communities in Latin America and the Caribbean. In 2020, average temperatures exceeded the historic record by 4.2°C in Florianopolis, Brazil, 2.4°C in Ciudad Juárez, Mexico, or 4.9°C in Santa Rosa, Ecuador. This same year, Brazil, Paraguay, and Bolivia experienced the worst drought in half a century, and thirty tropical storms were counted in the Atlantic basin, the highest number on record. The socioeconomic impacts of climate change are on track to be similar or higher, by 2030, to the devastation that the Covid-19 pandemic caused in 2020, which saw extreme poverty jump by 5 million, to 86 million, in the region.

The good news is that countries in Latin America and the Caribbean are acting. Eleven countries have pledged to reach net-zero emissions, most of them by around midcentury. Many agree that climate action can be in their best interest. We know that, done right, the transition to a carbon-neutral economy can bring 15 million net new jobs and 1% of additional GDP growth by 2030 to the region, even after the costs are considered. This is why climate action is one of the pillars of Vision 2025, the IDB Group's pathway for achieving inclusive and sustainable growth.

Yet, delivering on the Paris Agreement goals is a gigantic task. In Latin America and the Caribbean, it means that 7 to 19% of GDP, or up to US$1.3 trillion of public and private spending, will need to be aligned each year with climate change goals. International finance will be essential but is bound to be insufficient. Transforming our economies is only possible if all domestic stakeholders also understand what the transition to net-zero emissions requires, why it can be in their interest, and how they can act on enabling it.

To assist in this task, this report demystifies what financing the transition to net-zero emissions means. It provides a menu of options for governments to consider and embark in the transition towards carbon-free prosperity. It shows how 15 transformations that rely on existing technology can help deliver deep emission reductions, acting on electricity; transport; agriculture, forestry and land-use; buildings; industry; and waste management.

This report then presents evidence of the type of social and economic benefits that countries in the region can expect from the transformations. For instance, reducing the use of fossil fuels equals less polluted cities and communities, bringing positive health impacts. Public transit can save billions of dollars' worth of time currently wasted in congestion. Renewable energy, which is the cheapest form of electricity in the world, can deliver lower and more stable prices for customers and businesses. Forest and mangrove conservation comes with ecosystem benefits. And a circular economy can improve the competitivity of industrial firms.

But change will not happen by itself. Dozens of barriers, listed in the report, prevent public and private actors from investing in the transition to a carbon-neutral economy. Among them, regulations often favor incumbent technologies.

Key infrastructure may be missing. Financing is difficult. Critical actors may lack information or the capacity to act. Change will create winners and losers. Governments wishing to enable the public and private financing of climate action can map these barriers, and act accordingly, by planning regulatory reforms, infrastructure deployment, fiscal reforms, capacity building, information campaigns, and measures to compensate the distributional impacts and ensure a just transition.

The point of this publication is not to say that decarbonizing is easy, or that countries should implement all the government interventions listed immediately. On the contrary: one key finding is that the transition to net-zero emissions economies is a complex and difficult one, that cannot be solved by a handful of government agencies or using only one or two policy instruments. It would instead require a 'whole-of-government' approach, where every ministry and all levels of governments, including states and cities, play a role.

Countries wishing to decarbonize will need to do so in their own terms, starting from a diagnostic of the challenges they face, their development priorities, and what fiscal space, capacity, and political capital they can use to impulse change. In this sense, the 15 transformations we provide are but a list of options that governments may consider.

There will be no one size-fits-all-solution. The Paris Agreement, which has been ratified by all IDB members, establishes the need to ground climate action on the principle of common but differentiated responsibilities and respective capabilities. Each country should thus design its own tailor-made action plan to ensure a just transition and orderly transition to a decarbonized economy that brings net benefits to its firms, households, and communities.

We hope you will count on the IDB as a close partner to Latin American and Caribbean countries embarking on this process. We aim to provide $24 billion in climate finance over the next four years, and in 2021 we approved nearly $4.5 billion for climate-related operations, the highest amount in our history. From the IDB, we will continue to invest, support, and put all our knowledge at the service of this vital task, as we have done in the past. With this publication, we are taking another important step toward achieving this common goal.

Benigno López Benítez
Vice President for Sectors and Knowledge
Interamerican Development Bank

All countries are facing the three structural crises of climate change, biodiversity loss, and devastating pollution, impacting people's lives and economic prospects. Today, we are also facing the pandemic and war in Ukraine. Developing countries are most affected as they often lack the resources to finance the recovery. Cooperative agreements and arrangements across national borders are thus critical to continue investing in sustainable development.

At the same, we are experiencing tectonic shifts in global narratives: deglobalisation is now discussed even in Davos circles, and at the same time the zero-carbon economy or regenerative economy are becoming the new aspirations for modernization. Some trends are not controlled, such as digitization and robotization. Others can be intentional, such as the transition to a low-carbon economy, which is unavoidable given the rapid decline in the cost of renewable energies.

All these shifts are where, in our view, opportunity lies. How can we anticipate future trends to capture value, jobs, and decision-making power? In a world where many countries are eager to reclaim their national sovereignty to ensure their security of supply of energy and strategic goods, the nationally specific, bottom-up approach of the Paris Agreement and of the 2030 Agenda remain robust foundations on which to build national action and global cooperation.

Latin American and the Caribbean, where development pathways have historically been dependent upon the patterns of globalization, are in the front line. The transformation to a carbon neutral and biodiversity positive economy can be a way to embrace change. The region can play an active role in the transformation domestically and contribute to setting the norms and standards for the global economy of the future.

Time is short to guarantee we can stop the worst impacts of climate change. The recent Stockholm+50 conference showed that only one tenth of the hundreds of global goals agreed upon since 1972 have been achieved. Countries need to step up their institutional capacity to anticipate change, manage it, and coordinate public and private actors. It is imperative that politics and policy serve an agenda of action. It is a time to frame dialogues and analysis on the "how", and to do this with actors on the ground.

Science must play a central role in framing decision-making. We know that carbon neutrality is needed between 2050 (for 1.5°C) and 2075 (for 2°C) and that other gases must be curbed too. Emission reductions at this scale require rapid transformations, far beyond what has been observed in the past, across all components of the economic system, covering energy, urban shapes, infrastructure, industry, waste, land, and ecosystems.

Such drastic transformations in turn require profound changes in technologies but also in social, economic, institutional and policy conditions. Science shows that meeting climate objectives can be compatible with broader sustainable development objectives if action is implemented without delay, is guided by a strategic vision of transformations, and is enabled by domestic policy packages and international cooperation.

This publication aims at bringing science closer to the policymakers occupied with the 'how' to embrace a near zero-carbon world. We hope that countries that are set to explore national pathways to investigate how the rapid and far-reaching transitions required globally can happen in their country will find in this report guidance to translate those pathways into concrete policies.

Our contribution to this publication has been to mobilise the body of knowledge emerging from our community of international and in-country experts -the Deep Decarbonization Pathways (DDP) network - which has been working with decision-makers in more than 30 countries, notably in the Global South. Our work has shown the relevance for countries to explore techno-economic development pathways, back casting from their mid-century emission and socio-economic objectives to inform short-term investment decisions.

Based on these scientific assessments, experts from the DDP network have been advising their governments to pay attention to the risk of carbon lock-in, and to make sure that urgent decisions for economic recovery or reactions to energy prices shocks do not lead to investing in assets that would become stranded in a decade or two, once the zero-carbon economy has become the new normal. They have also performed in-depth investigations of the levers, opportunities and challenges associated with decarbonising complex sectors, such as transport, industry, or agriculture and land-use, that tend to be poorly represented in existing emission reduction plans.

One of the most important lessons we learned concerns the importance of stakeholder engagement. Co-constructing decarbonization scenarios and policy packages to enable them is an essential means for these scientific assessments to serve an action agenda. Only an in-depth political debate at national and subnational levels can ensure that national transformation pathways are a robust source of inspiration for all players. A broadly accepted strategy is the only guarantee, for investors, of stable incentives over time.

The work of the DDP network has shown that national transitions can be initiated using existing technologies at low and often net-negative financial cost. Usually, these transformations have large net economic benefits when external economic and environmental costs and benefits are factored in. However, implementation requires clarity about the choices to be made in the transition, about the concrete policies and actions that can be envisaged, especially concerning those who may lose from change, the measures adopted to manage the socio-economic costs of the transition, and the opportunities for international cooperation.

IDDRI will continue to support governments in developing effective and acceptable climate strategies. We are thankful to strategic partners such as the IDB who trust in the scientific and country-driven approaches, and hopeful this publication will make a difference for committed governments.

Sebastien Treyer
Executive Director
Institute for Sustainable Development and International Relations (IDDRI)

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Executive Summary

The Paris Agreement sets the goals of keeping global warming to well below 2°C and as close to 1.5°C as possible compared to pre-industrial levels, making all economies resilient to climate impacts, and ensuring that financial flows are consistent with these objectives (UNFCCC, 2015). The task is enormous: the transformations needed will require realigning 7% to 19% of GDP worth of private and public spending every year (Galindo Paliza et al., 2022).

To reach its temperature goals, the Paris Agreement and the subsequent decisions of its parties give central importance to emission-reduction strategies, decided by and for individual countries, following the principle of common but differentiated responsibilities and respective capabilities. This can take the form of Nationally Determined Contributions (NDCs) or Long-term Low-emission Development Strategies (known as LEDS, LT-LEDS, or LTS). At the 2021 UN Climate Change Conference in Glasgow, the parties acknowledged the need to decarbonize the global economy by 2050 if possible, and by the early second half of the 21st century for the 49 parties classified as least-developed countries (United Nations, 2021). Responding to this framework and to an increasingly clear mandate from corporations and the public, more than 50 countries globally – including 11 in Latin America and the Caribbean – have enacted targets to reach net-zero carbon or greenhouse gas (GHG) emissions, and more than 140 other countries have announced or are considering similar targets (Net Zero Tracker, 2022).

Reaching net-zero emissions will require action from companies, households, and government agencies from many different sectors of the economy. The three most relevant GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (IPCC, 2021). Globally, direct GHG emissions come from industry (26%), electricity and heat production (24%), agriculture, forestry, and changes in land use (21%)—in which agriculture accounts for about half of emissions and forestry and land-use change account for the other half of emissions—transport (14%), other energy (10%), and buildings (6%) (Lamb et al., 2021). In Latin America and the Caribbean, emissions in 2018 came from agriculture, forestry, and changes in land use (44%), followed by transport (15%), electricity (13%), manufacturing and industry (10%), waste (6%), and buildings (3%), while the remainder (9%) was linked to fugitive emissions and other fuel combustion processes (WRI, 2021).

In this paper, we search the academic literature and reports from international government agencies and think tanks to provide a list of 15 transformations that countries can consider using to reach net-zero emissions, benefits that are associated with them, barriers to their implementation, and a set of policies that governments can use to lift these barriers in each sector and enable the transitions. We find that getting to net-zero emissions is *technically feasible* (IPCC, 2022). This means that analysts around the world have identified existing technology and behavioral changes that, if enabled by appropriate government interventions, can deliver a carbon-neutral economy.

The transition can be done with parallel and immediate action across sectors, chiefly to replace fossil-fuel power plants with renewables ones; electrify transport, buildings, and other energy uses as much as possible; replace individual cars with public transport, biking and walking; upgrade agriculture practices; stop deforestation and preserve and expand forests and other high-carbon ecosystems such as peatlands; adopt healthy diets that reduce land used for food production; improve energy and material efficiency and transform industrial production by mostly replacing fossil fuels with low-carbon electricity, hydrogen, and synthetic fuels; and improve waste management by reducing waste, improving recycling, and introducing circular economy frameworks (Fay et al., 2015; Waisman et al., 2019; Bataille et al., 2020; DDPLAC, 2020; IDB and DDPLAC, 2019; IPCC, 2022).

Getting to net-zero emissions can bring economic and social benefits. The transformations listed above can come with local benefits, such as lower energy costs owing to record-cheap renewable energy, operating savings due to electromobility, the benefits of avoided air pollution to health, reduced time wasted in traffic congestion, better health outcomes linked to physical exercise, reduced accidents, healthier diets, better industrial and agricultural productivity, and ecosystem services including biodiversity preservation, provision of fresh water, and attraction of tourism. Getting to net-zero emissions by 2050 can bring net benefits amounting to $41bn in Costa Rica, $140bn in Peru, and $7bn in Chile (Groves et al., 2020; Quirós-Tortos et al., 2021, Benavides et al., 2021). In Latin America and the Caribbean, net benefits can increase GDP by 1% by 2030 (Vogt-Schilb, 2021). Millions of jobs can be created during the transition if governments align sector strategies, labor regulations, and education policies with climate change goals (ILO, 2018; Saget et al., 2020). These local benefits are in addition to the main global benefit of the transition to net-zero emissions, which provides the initial motivation for undertaking it—avoiding the worst climate damages and their socioeconomic impacts (Hallegatte et al., 2016; IPCC, 2022).

Many barriers prevent the uptake of net-zero solutions. These include, among others, hurdles related to infrastructure, regulations, public and private finances, access to and capacity to act upon information, and political economy issues (IDB and DDPLAC, 2019). For instance, the absence of sidewalks and dedicated lanes and traffic lights can make walking and biking less convenient and more dangerous than private transportation in a car. Market design and tariff schemes can disincentivize the use of renewable energy or electric buses despite lower lifetime costs. Energy subsidies can incentivize the use of fossil fuels instead of renewables, and the upfront costs of insulating buildings and switching to electric stoves, electric water heaters, and efficient heat pumps pose a significant barrier for most households. Farmers often have limited capacity to monitor or improve their use of synthetic fertilizers. Further, most households only have partial information on the relative carbon content and health benefits of different diets. The phasing out of coal, oil, and gas power plants can be made difficult by the negative impacts it has on affected workers and communities, despite the net-positive socioeconomic impacts for society overall. Barriers like these collectively prevent the transition to net-zero emissions from happening quickly, despite scientific evidence and political mandates in favor of taking climate action.

Dozens of government interventions will thus be needed to lift the barriers that prevent the private and public sectors from investing in net-zero-emission solutions. These include, among others, actions to build the necessary infrastructure, regulatory reforms, getting prices right or providing targeted subsidies, building capacity, providing information, and managing the political economy. For instance, governments can build the sidewalks and bike paths that support safe walking and biking. They can redesign public transport and electricity markets to enable profitable business models for electric bus drivers and renewable energy operators. They can mandate a fraction of new buildings to be well insulated or ready for distributed solar energy, leveraging lower costs at the construction phase, or they can subsidize heat pumps or electric cookstoves. Governments can refocus their agriculture programs on GHG-conscious practices and inform citizens about healthy diets based on low-emission footprint products. They can ensure workers and communities affected by the downsizing of coal power plants participate in the design of just transition policies and receive compensation and support to adapt. Governments can also use public procurement processes to create markets for green materials and lead the way with electric fleets, energy-efficient public buildings, or environmentally conscious meals in public schools and offices.

These examples are not meant to rank the most important emission-reduction opportunities, benefits, barriers, or government interventions to enable the transition. Instead, our work joins many prior contributions in showing that climate change mitigation is a complex task. It requires a comprehensive whole-of-government approach that emphasizes sustainable development (Fay et al., 2015), as opposed to relying on one most-important instrument, as carbon pricing is sometimes described (see also Lilliestam et al., 2021), or depending on one or two key ministries, such as Environment or Finances. Many prior papers have emphasized the importance of assessing sectoral transformations towards long-term decarbonization goals (e.g., Clarke et al., 2014; Rogelj et al., 2019., Bataille et al., 2016; Geels et al., 2019; Arregui et al., 2020); provided examples of sectoral policies that can be used to reduce emissions (Roelfsema et al., 2018, Fekete et al., 2021); or underlined the many development and economic benefits to decarbonization, including for a sustainable post-Covid recovery (Boehm et al., 2021; Cavallo et al., 2021). This work is the first, to our knowledge, to systematically list transformations that can help countries to reach net-zero emissions in major emitting sectors, list the benefits associated with the transformations, and explicitly distinguish sectoral transformations and policies required to unlock them, all based on a diagnostic of barriers preventing transformations from happening. While our work is relevant at the global scale, we also provide a novel focus on Latin America and the Caribbean.

Local contexts should be the basis for prioritizing government intervention. Governments may consider different factors when developing their own emission reduction plans, such as (1) the urgency of action to reach net-zero emission goals, which depends on whether inaction locks in carbon-intensive development and makes later action more difficult (Vogt-Schilb et al., 2015), (2) synergies between emission reduction actions and development priorities; and (3) fiscal space, institutional capacity, and political capital available to invest in making each government intervention happen. What government agency and level of government (e.g., municipal vs. federal) should intervene also depends on the country context, chiefly on local institutions and legal attributions. In that sense, this work is but one input that governments can use to design decarbonization strategies.

The rest of the document is structured as follows. The following six sections (electricity, transport, agriculture, forestry and land use, buildings, industry, and waste) each include one or more key transformations to reduce GHG emissions towards net zero. Each transformation starts with the definition of a vision statement describing its aspired goal. It then describes the changes necessary to achieve this vision, which benefits could come with implementing the vision, which barriers are to be considered, and which policies may effectively reduce these barriers. The last section discusses the findings and concludes.

Electricity

Electricity and heat generation caused 24% of global GHG emissions in 2018 (Lamb et al., 2021). In Latin America and the Caribbean, the sector is responsible for 13% of total GHG emissions (WRI, 2021). The energy sector (including electricity, heat, buildings, and industrial use of energy) emitted 33.5 $GtCO_2$ in 2021, or approximately two thirds of global emissions (International Energy Agency [IEA], 2021a). Almost half of these emissions were caused by coal, around 20% by natural gas, and the remainder was linked to oil and other fossil fuels. If countries follow their current NDCs, more than 20% of electricity generation would still be based on coal in emerging and developing countries in 2050 (ibid, p.39), although this may change with updated NDCs that are aligned with a global push to net zero (IEA, 2021b). In Latin America, total electricity demand is expected to almost double by 2040, to a total of approximately 2300 terawatt-hours (TWh). Light and heavy industry, cooling and ICT, and small appliances are projected as main growth drivers (IEA, 2021c).

Transformation 1

Accelerate carbon-free variable and flexible electricity generation through sources such as solar, wind, geothermal, and hydropower

The transformation

Clean electricity is the backbone of the transition to net-zero emissions (Clarke et al., 2014; Audoly et al., 2018; Williams et al., 2012b; Rockström et al., 2017; Bataille et al., 2020; Tong et al., 2019; Williams et al., 2021; Davis et al., 2018; Bataille et al., 2016). This transformation focuses on building sufficient renewable sources, especially solar and wind but also geothermal, hydropower, nuclear, and other flexible electricity generation plants—considering country-specific properties (e.g., topographical and geographical conditions as well as resources)—to cover domestic electricity demand, along with sufficient clean flexible power to meet demand peaks.

Benefits

A key non-climate benefit from clean electricity is financial savings in the form of long-term stability of returns for public and private investors, which is ideally translated into lower electricity prices for customers, as wind and solar electricity is now the cheapest source of energy globally, and the cost of batteries is falling rapidly (IEA, 2021a). While regional differences exist depending on input factors such as wind or sun, utility-scale solar has reached global average prices of $0.04 USD in competitive procurement processes, which is 27% less than the cheapest fossil alternative (International Renewable Energy Agency [IRENA], 2020a). Decreasing fossil energy input, such as oil and coal, may also reduce the dependence of countries on energy imports (IRENA, 2019a). Most countries can become more energy independent by phasing out fossil fuels and deploying renewable generation (ibid, p.36). Additionally, renewable electricity generation can be more easily decentralized, which can help provide electricity services in hard-to-connect areas (Murphy et al., 2014; IRENA, 2017). Renewable electricity also allows for the integration of households and commercial buildings as electricity prosumers (i.e., being consumers and providers of electricity at the same time). Renewable energy generation is less water-intense than fossil fuel generation, improving access to water and water security (IRENA, 2015). Lastly, the whole value chain, from manufacturing to installation, operation, and maintenance to disassembly and recycling, offers opportunities for increased economic activities and sustainable jobs (Llera et al., 2013; ILO, 2018). The International Energy Agency (IEA) estimated that the net-zero transition could add a net 9 million jobs globally by 2030 (IEA, 2021). Looking further, the International Renewable Energy Agency (IRENA) and the International Labor Organization (ILO) estimate that construction, operation, and maintenance of renewable generation can create 43 million jobs globally by 2050 (IRENA and ILO, 2021).

Barriers

The biggest barriers to a take-up of large-scale renewables are the necessary upfront capital, energy market designs, and missing infrastructure such as transmission lines (IEA, 2021).

Wind and solar energies are capital intensive, despite their lowest lifecycle costs based on free fuel. Capital markets sometimes inadequately understand renewable generation, limiting the availability of funding. In developing countries, the higher weighted cost of capital compounds this problem. In most countries, electricity systems and markets were created around fossil fuel sources—which can be adjusted to produce more or less power according to demand variations over minutes, hours, days, and seasons—without consideration of the character of variable sources.

Infrastructure is lacking to support renewable energy (IRENA, 2016). This includes transmission and distribution networks being out of date, as well as missing auxiliary infrastructure for renewable generation, such as adequate storage or technical upgrades at consumer sites (IEA, 2020).

Existing regulation can inhibit the deployment of renewable energy generation. This includes regulation on the siting of renewables, security standards for fossil fuel plants being applied to renewable energy, the connection to the grid, and specifications on use of plants and producer payments. In many cases, such as hydropower, necessary social and ecological risk mitigation slows down the realization of new projects (IRENA, 2020b; International Finance Corporation [IFC], 2015). Moreover, while renewable resources are often available in a decentralized way (e.g., rooftop solar), which minimizes the need for new transmission, grid regulations often impose connection barriers on such small-scale generation technologies.

Existing energy planning can be outdated and inconsistent with net-zero emission goals. New technologies need to be considered on both the demand and supply sides. In too many countries and regions, the understanding of long-term demand for energy does not reflect significant changes such as the need for electric vehicle charging or energy efficiency gains (see below), does not include renewables, or uses outdated cost assumptions for renewables, leading to a poor understanding of the benefits lifetime cost savings of deploying renewable energy generation, which is significantly different from a traditional baseload-based system (Gielen et al., 2019).

Government interventions

Fiscal incentives can support the deployment of renewable energy and required supporting infrastructure. This includes fiscal measures, such as subsidies for investments by households or companies, accelerated depreciation, public guarantees, and private-public partnerships (Krogstrup and Oman, 2019).

Support mechanisms such as feed-in tariffs, auctions, and other forms of price-regulating measures have also been effective (IRENA, 2020b; Rockström et al., 2017).

Targeted funding can be offered for upgrading transmission lines and distribution grids and deploying storage infrastructure (e.g., batteries, pumped hydro, and hydrogen) (IEA, 2020a; Gielen et al., 2019). Similarly, a carefully designed phasing-out of fossil fuel subsidies, with measures to mitigate social impacts, must accompany any updating of the fiscal incentive scheme (IEA 2021b; Parry et al. 2021).

Functioning financial systems and capital markets can be created or strengthened. Financial instruments can help lessen the higher upfront cost of renewables and their associated infrastructure. Green or sustainability linked bonds can leverage both domestic and international private markets (IRENA, 2020c). International financial institutions such as development banks can provide loans that decrease the cost of capital. Increasing transparency (e.g., by gathering specific climate finance data) can also help address credit market challenges that lead to under-banking of renewable projects (Krogstrup and Oman, 2019).

Updated regulations can promote renewable generation. GHG emission standards and renewable portfolio standards can help ensure that private operators invest in renewable energy (IRENA, 2018). Land-use regulations can be updated to pre-establish renewable electricity generation zones, including accelerated approval for new sites while ensuring mitigation of social and environmental risks. Safety regulations can be tailored for renewable energy, reflecting how the standard regulatory regime for handling hazardous fossil fuels is not required (IEA, 2020a). Electricity market design can give priority to the use of variable renewable sources over incumbent fossil fuels with higher marginal production costs. Net metering of electricity used by prosumers can improve the financial incentives for distributed renewable energy.

Variability can be addressed by deploying flexibility, storage, and demand management options. Inexpensive variable wind and solar can provide 60–90% of needed power but must be supported by sufficient active demand management and flexible clean generation (e.g., impoundment hydropower, geothermal, and perhaps nuclear, especially in countries with already existing nuclear generation, as well as fossil fuels with carbon capture and storage [CCS] in some cases) and storage over multiple timeframes (e.g., batteries, pumped hydro, green hydrogen) to balance supply and demand (Sepulveda et al., 2018; Jenkins et al., 2018; Baik et al., 2021; IEA, 2021d).

Better planning can align power expansion plans with net-zero emissions goals. Funding can be provided to promote energy supply and demand analyses that consider different regional weather patterns and usage scenarios. These provide an estimate for needed on-demand firm power supply through storage or hydro in the case of low supply through renewables. In Chile, the official long-term energy plan is being updated to be made consistent with the country’s goal to reach net-zero emissions by 2050; it anticipates, for example, the higher electricity demand that electric mobility will bring. It also anticipates the need for additional transmission lines and storage sites to deal with increased wind and solar generation (Ministerio de Energía Gobierno de Chile, 2021).

Transformation 2

Phasing out all fossil fuel electricity generation, such as coal, natural gas, and diesel

The transformation

Continuing using already existing fossil fuel energy infrastructure and adding fossil projects still in development would emit more GHGs than what is consistent with keeping warming to 1.5 °C. Approximately 50% of these emissions are associated with electricity generation (Tong et al., 2019). In Latin America and the Caribbean, existing and planned power plants, especially gas power plants, would similarly emit twice as much GHGs as what scenarios reviewed by the Intergovernmental Panel on Climate Change (IPCC) suggest would be consistent with the region meeting 1.5 °C or 2 °C targets (González-Mahecha et al., 2019). This highlights the importance of phasing out all fossil-based electricity generation as soon as possible, especially those power plants that can be replaced by variable renewables, even if amortization periods have not been reached for certain generation projects at the time of phase-out. This transformation also includes immediately stopping the development of new fossil-based projects and considering explicit +90% CO_2 capture and permanent storage for projects under construction (IEA, 2021d).

Benefits

Phasing out fossil fuel provides health benefits from cleaner air, water, and soil. For each TWh produced, coal causes 24.5 additional deaths and more than 13,000 illnesses, oil 18.4 deaths and more than 9,500 illnesses, and natural gas 2.8 deaths and more than 700 illnesses (Markandya and Wilkinson, 2007). Water withdrawal for power generation can be decreased by up to 95% by 2050 if 100% of the energy in the global energy system is provided by renewables (Lohrmann et al., 2019). Long-term import dependence on fossil fuels can also be reduced (IRENA, 2020d, 2019b), and the negative impacts of large oil rents on economic diversification, innovation, institutions, and political stability can be mitigated (IRENA, 2019a). Additionally, many of the benefits mentioned in Transformation 1 (e.g., energy security and reduced costs) are linked to phasing out fossil fuels.

Barriers

Much government energy planning continues to count on the use of fossil fuel power plants and extraction (IEA, 2018; SEI et al., 2021). The often anticipated but not factual decrease in power sector reliability (e.g., because of the loss of on-demand energy sources to balance variable renewable generation) poses another barrier. This is linked to the lack of technical capacity and knowledge to integrate variable renewable generation without harming reliability (Sepulveda et al., 2018).

The negative impacts on regions and workers who depend on fossil fuel industries can be a key barrier. This includes potential losses within the coal industry value chain (e.g., mining and transport) and the employment impacts on communities (GIZ, 2021). For instance, in Chile, 4,000 people worked in coal power plants when the government decided to start planning for coal phase out. Specific communities can also be affected; in the most exposed communities of Chile, coal power represents almost 4% of local GDP, and 7.1% of residents of these communities work in a coal power plant (Saget et al., 2020). Legal aspects, such as long-term contracts with extraction businesses and utilities, can pose additional barriers.

Political economy considerations for the short-term financial revenue of extracting fossil resources slow down the dynamics of the phase out (IRENA, 2019a). The fiscal impacts of fossil fuel phase out can be important for countries or sub-national governments who rely on royalties. Globally, fossil-fuel-reliant countries could see a 51% drop in government oil and gas revenues in a shift to a low-carbon world over the next two decades (Coffin et al., 2021). In Latin America and the Caribbean, more than $3 trillion in oil royalties and more than $200 billion in natural gas royalties are at risk of disappearing by 2035 (Solano-Rodríguez et al., 2021; Welsby et al., 2021).

Government interventions

Mandatory targets for the phase out can be established, taking into account that early termination of existing power purchase agreements might result in additional costs (IEA, 2018). Financial incentives for early phase-outs can be used, and any remaining subsidies for fossil-based technology need to be phased out (IEA, 2021d). In order to ensure the integrity of public resources, beneficiaries of such incentives should not be building or planning to build new fossil fuel infrastructure (including natural gas). Policies available to decrease the social and economic impact of a fossil fuel phase-out and ensure a just transition for affected regions and communities include providing financial benefits to ease the potential impact of job losses, reskilling and upskilling incentives, and broader financial support for the affected regions to attract other sectors and businesses (GIZ, 2021; Saget el al., 2020). Resource-rich countries can highlight the political economy of long-term opportunities of phasing out fossil fuels early. Many countries will need to plan for the diversification of their economy and moving fiscal regimes away from fossil fuel dependency (Delgado et al., 2021). This can begin by analyzing and planning for the impacts that a fossil fuel phase-out will have on the public and private financial systems, banning new investments that would increase that impact in the future, scheduling the retirement of existing fossil-fueled assets, and establishing a financial strategy to mitigate the impact of the reduction of fossil fuel royalties (ibid).

Transport

The transport sector is responsible for 14% of global GHG emissions (Lamb et al., 2021). Road transport such as cars, trucks, and buses represents 75% of transport emissions (IEA, 2021d). In Latin America and the Caribbean, transportation is responsible for approximately 15% of net GHG emissions, and it is one of the fastest-growing sources of emissions in the region—on par with electricity generation (WRI, 2021). Demand and related emissions are set to grow, which are mainly driven by urbanization and GDP and population growth. However, transport emissions will need to instead drop to one third of 2019 levels by 2050 to meet climate change goals.

Transformation 3

Reduce individual motorized transport and increase public transport, walking, and biking

The transformation

By 2050, urban passenger transport demand is expected to increase 2.3 fold (ITF, 2021), and 3.5 fold in the Latin America and Caribbean region (Blanco et al., 2022). Individual cars and motorcycles tend to emit more GHGs per passenger kilometer than public transport options such as buses, trams, and metros. The footprint of public transport options is much better when they achieve high occupancy rates, and when they run on electricity instead of fossil fuels (see also next transformations). Walking and biking always emit far less then private cars (IPCC et al., 2014).

In urban areas of developed countries, approximately 52% of mobility is provided by private motorized transport, while public transport and non-motorized transport account for 21% and 26%, respectively. In developing countries, this share is 33%, 27%, and 40%, respectively, with an increasing share of private motorized transport in recent years (Sustainable Mobility for All, 2017). For instance, the city of Bogota has experienced a decrease of use of mass public transport from 40% to 35% since 2015 (Blanco et al., 2022). Apart from private cars, motorcycles are becoming more popular in Latin America and the Caribbean.

Following the avoid-shift-improve framework, strategically avoiding transport is the most desirable option but also hardest to achieve (Creutzig et al., 2018). This can be done by using urban design that reduces the need for mobility or using technology to increase teleworking and reduce the need for in-person meetings to do business or interact with the government.

Shifting from individual motorized modes such as cars and motorcycles to public transport, biking, and walking can further greatly reduce emissions. Meeting the goals of the Paris Agreement requires a reduction of trips by private cars of at least of 8% from current levels by 2030 (Boehm et al., 2021).

Benefits

A reduction of individual motorized transport reduces health system costs by reducing pollution and accidents (Vohra et al., 2021; Douglas et al., 2011; Suhrcke et al., 2006). Public transport can also reduce congestion and accidents (IDB, 2021b). In Costa Rica, for instance, the costs of congestion, traffic accidents, and negative impacts of pollution on health amount to 5 billion USD per year; reducing individual transport can reduce these costs (Groves et al., 2020). In the United States, 87 billion USD in productivity gain would have been realized without traffic in 2018 (World Economic Forum [WEF], 2019). In the cities of La Paz and Medellin, cable cars have proven to save time for commuters, positively impacting their transport decision and even employability (Yañez-Pagans et al., 2019).

In the cities of Lima, Perú and Cali, Colombia, investments in bus rapid transit systems, combined with reforms to the informal bus sector, resulted in large in-vehicle travel-time savings and reductions in local and global emissions from transit vehicles in the corridor (Scholl et al., 2015).

Additionally, shifting away from motorized individual transport allows for a redefinition of public space, such as reviving streets as pedestrian areas or creating green areas that improve the attractiveness of neighborhoods and have climate co-benefits, such as reducing temperatures or providing flood protection (Foster et al., 2011; Pincetl and Gearin, 2005). Free parking for cars in the US equaled a USD 127 billion subsidy in 2002 (Shoup, 2021)—this money, if transformed into parking charges or property taxes, could be redirected with social benefit if motorized individual transport is reduced. In a context where congested streets have become an overused common resource, actions to redistribute surface use (and therefore use of time) can improve social equity.

Barriers

The current infrastructure favors cars over pedestrians and cyclists, and people will not switch to biking or walking if doing so poses a significant risk to their safety. Separate lanes and dedicated lighting are often lacking for bikes. In developing countries, sidewalks for pedestrians and dedicated lighting are also often missing. In contrast, many jurisdictions mandate the provision of car-centric infrastructure, such as requirements for parking spaces at the building or neighborhood level. Moreover, investments in public transit infrastructure are often made in isolation from land-use planning, resulting in a lack of safe pedestrian infrastructure to access stations and the continuation of sprawling, low-density land-use patterns that are unconducive to supporting transit ridership and the use of active modes. This makes alternatives to cars less convenient and more dangerous. Data from the European Union shows that pedestrians and bikers make up 21% and 8% of road deaths, respectively (European Transport Safety Council [ETSC] et al., 2020).

Public transport is often insufficiently attractive in terms of frequency, connectivity, and quality of vehicles (Yañez-Pagans et al., 2019). Moreover, compared to individual cars, which provide a point-to-point solution for users, public transport may require line and mode changes, and be poorly integrated with walking and biking. Public transport can also be unsafe, especially for women (Martínez et al., 2018). Issues with public transport are especially true for Latin America, where 80% of people live in cities (Atlantic Council, 2014) and where public transport has not kept up with urbanization (Scholl et al., 2021). Gaps in public transit coverage in communities living in far-flung peripheries of cities and a lack of integration of transport options result in long travel times requiring multiple transfers, unaffordable fares, higher levels of immobility, and a reliance on informal modes, such as privately organized and often poorly maintained minibus transport, particularly for poor populations (Scholl et al., 2015). The inefficient splitting of urban transport into different transport zones poses another barrier. While a split of responsibilities between municipalities, districts, and the federal level delays decision-making and the implementation of upgrades, it also adds to complexity in the customer journey, such as buying several tickets for one trip or paying multiple times for a trip within a zone due to a brief crossing of another zone (Blanco et al., 2022).

Car use is largely incentivized in current transport policies, for instance, through "hidden subsidies" for individual motorized transport, such as the socialization of costs for free parking (see above) and free road use (Mattioli et al., 2020). Moreover, funding for public transport is scarce in Latin America and the Caribbean—even more so since the start of the Covid-19 pandemic. This leads to delays in transport maintenance and infrastructure upgrades, ultimately contributing to a decrease in the attractiveness of public transport options (Blanco et al., 2022).

Labor regulations and existing employer policies can work against teleworking. For instance, health insurance policies can leave accidents at home uncovered, or employers can insist on their employees being physically present at specific offices.

Government interventions

To reduce the demand for transport, governments can integrate accessibility goals into land-use planning at every level of urban and rural development (OECD, 2021). Governments can create zoning regulations and mandates to ensure that new developments are designed to enable short transport routes, for instance, by increasing their density (Ribeiro et al., 2019) and by ensuring that the infrastructure of daily life, such as schools, supermarkets, and pharmacies, are locally accessible—ideally at walking or biking distance (OECD, 2021).

Investment in infrastructure can be used to enable non-motorized and public transport. Public–private partnerships (PPPs) can be established to split costs, generate revenue streams, or improve the financial viability of infrastructure projects. They have been used for decades in Latin America and the Caribbean (Congressional Research Service, 2021; IDB Invest, 2020). Investment is needed to build dedicated public transport infrastructure such as rapid bus lanes and rails for tramways and subterranean metro systems (Yañez-Pagans et al., 2019). Within public transport options, the upfront cost, time required to build the infrastructure, and capacity increase are lowest for buses and bus rapid systems, intermediate for trams, and highest for metro. Infrastructure for biking and walking needs to focus on convenience and safety. Introducing bike lanes physically separated from car traffic and parked cars (to prevent "dooring") and bike-friendly traffic lighting is key for increasing bicycle use (Wegman et al., 2012). An easily accessible and broad network of public bikes, integrated with mass transit systems, can incentivize short trips and biking from a residential area to the next public transport station, usually referred to as the last mile (DeMaio, 2009). Infrastructure also needs to be upgraded for pedestrians, including the provision of safe crossings, walkways, and intersections (ETSC et al., 2020).

Better urban planning and management are also crucial to support public transport. These include coordinating land use with public transit, transit-oriented development strategies that cluster mixed land uses and higher-density developments around transit stations (Suzuki et al., 2013; Scholl et al., 2015), and making sure public transport lines effectively connect population centers to all commonly used leisure, work, education, and health service centers. Sustainable Urban Mobility Plans are a tool that can help support this more systematic and integrated planning approach. Improving the quality of public transport is also key, such as supplying more vehicles to increase frequency, providing on-demand public transport, using bus rapid transport systems to bypass congestion, and improving safety in public transport (Axsen et al., 2020).

Regulatory updates can promote the popularity of public transport, walking, and biking. These can include the definition of low- or zero-emission zones with preferential treatment for non-motorized transport or setting design standards for walkways and bike lanes (Hull and O'Holleran, 2014). Building codes can mandate cycling support facilities, such as covered secure bike storage in residential, commercial, and office buildings, and showers and locker rooms in office buildings (O'Neill et al., 2020). Conversely, car parking mandates can be reduced or eliminated, or the costs of parking increased to create additional revenue streams directed towards public transport improvements. To ensure relevance for users and social acceptability, regulations need to be designed and implemented in a participatory approach with public commuters and other stakeholders (Sohail et al., 2006). Transport zones should be reduced to a minimum to keep the management of public transport efficient, both for the public owner as well as for customers. Ticketing needs to be simplified, for example, by making tickets valid in various zones instead of only one zone (Blanco et al., 2022).

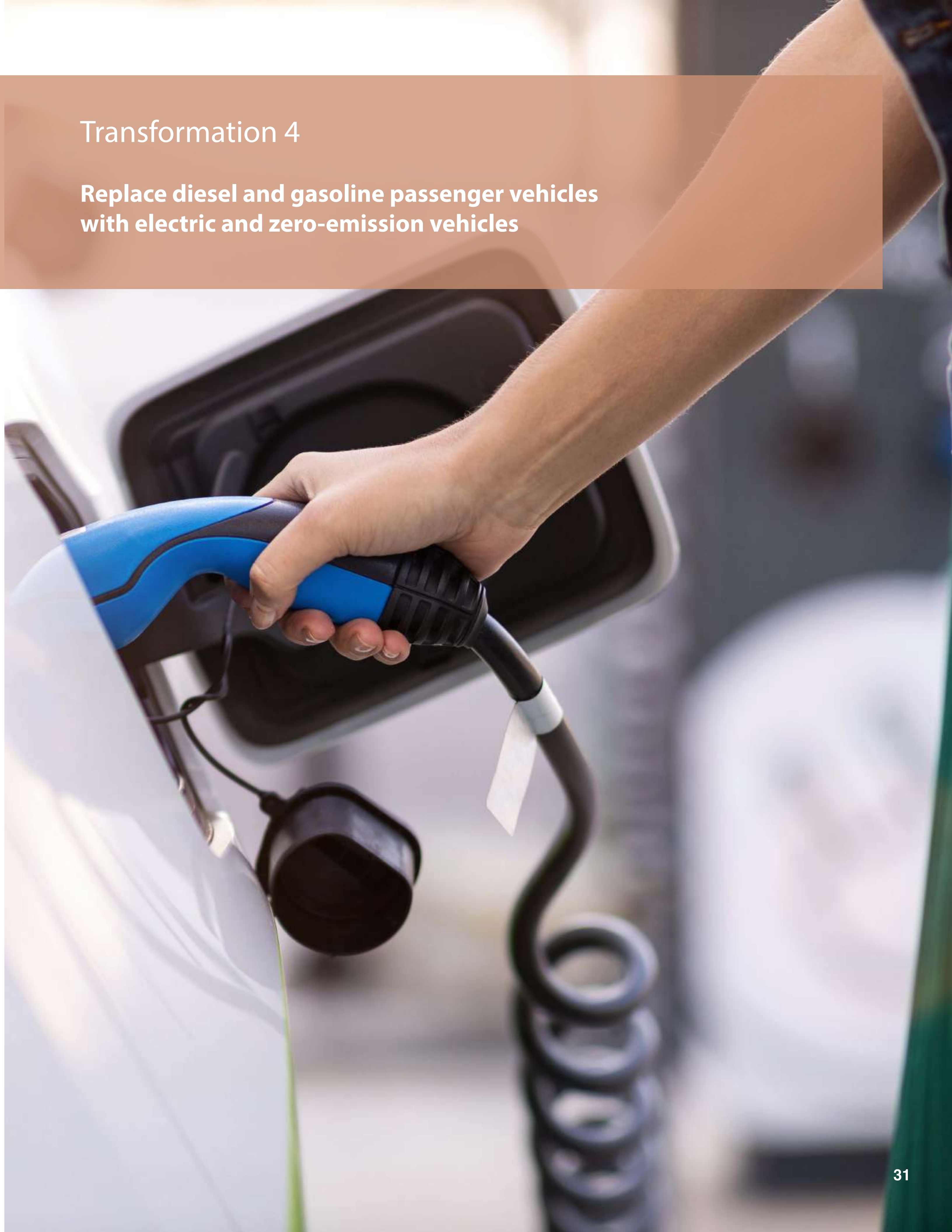
Governments can create financial incentives for alternatives to private transport. Public money can subsidize the price of public transport tickets for all or dedicated groups, create tax benefits for use of non-motorized transport (Cats et al., 2014), and reduce the purchase cost of passenger and cargo bikes (Martin et al., 2012). Conversely, road tolls, city tolls, and pricing for parking in public spaces can disincentivize car use (Mattioli et al., 2020). Road pricing policies can help internalize the environmental costs of private motorized transport and incentive lower carbon modes of transport such as public transit, walking, and biking. However, such policies will be more politically palatable in the context of investment in high-quality, socially inclusive, and accessible public transit systems (Scholl et al., 2014). Car trade-in programs known as "cash for clunkers," subsidizing the purchase of electric bikes, or public transport in return for discarding old cars can also be used

(World Economic Forum, 2021). To fund necessary maintenance and infrastructure upgrades, governments can create long-term plans laying out funding requirements. These plans can be used to involve both the private sector and bilateral or multilateral funding and attract funding from these sources. Public transport systems can also introduce land-value capture systems combined with TOD to create another stream of income to be used for essential investments (Blanco et al., 2022; Patermina et al., 2022).

Teleworking can be promoted by creating the necessary regulatory environment, for instance, by redefining occupational health standards to include coverage in home offices, or by mandating that employers have to allow a minimum number of days to work from home. Investments in home office infrastructure can be subsidized or tax benefits offered (Creutzig et al., 2018). Emerging from the Covid-19 pandemic, governments can take advantage of this opportunity, as research shows that disruption in travel behavior is an ideal catalyst to implement fundamental shifts (Williams et al., 2012a).

Transformation 4

Replace diesel and gasoline passenger vehicles with electric and zero-emission vehicles



The transformation

Most emissions from passenger transport by road come from the burning of gasoline or diesel in vehicles. The emission-free alternative, electric vehicles (EVs), represented 9% of global car sales (i.e., passenger cars and light commercial vehicles) in 2021 (IEA, 2022a), an increase of 100% compared to 2020, as their costs continue to fall and their charging networks grow (BNEF, 2021). In Latin America, approximately 100,000 electric and hybrid cars were sold in 2021. Replacing fossil fuel vehicles with EVs allows for the elimination of all tailpipe GHGs and local air pollutant emissions, assuming that the electricity comes from renewable generation. This transformation makes sense in all countries, even those where power generation currently comes from fossil fuels, when combined with policy to decarbonize electricity supply by 2050 (Audoly et al., 2018). In the IEA Sustainable Development Scenario, which is consistent with net-zero emissions between 2050 for developed and 2070 for developing countries, electricity demand for road transport in Latin America is expected to increase by 44 TWh by 2040, which is less than 5% of the total projected growth of electricity demand in the region (IEA, 2021c).

Benefits

Electrifying transport can bring financial benefits. Electric powertrains are substantially simpler, more reliable, and consume much less energy than fossil fuel alternatives, which, combined with electricity prices being typically lower than gasoline prices, can result in cheaper ownership cost over their lifetime. Lifecycle costs for electric buses are already lower than for diesel buses in some cases. In Mexico City and Santiago de Chile, the total cost of ownership for electric buses is 10% and 20% lower than the cost of incumbent fossil fuel technology, respectively (World Bank, 2019).

Electrification of transport also comes with health benefits associated with reduced local air pollution from phasing down fossil fuel use—cleaner air reduces the risk of cardio-respiratory disease (IEA, 2016). Indeed, the transport sector was responsible for approximately 11% (385,000 people) of all premature deaths due to air pollution in 2015 on a global scale, translating to 7.8 million years of life lost (Anenberg et al., 2019).

If electrification is achieved by replacing aging cars with newer ones, additional health benefits can be attained, as newer cars come with new or better safety features, including road assistance, collision sensors, airbags, anti-lock brakes, or better lighting systems. These safety upgrades can result in decreases of fatalities of up to 70% and a reduction of injuries between 40% to 70% (Ernstberger et al., 2015).

Lastly, electrifying transport reduces dependence on oil imports for non-oil extracting countries and has positive impacts on price variability, as electricity prices, if predominantly from renewable generation, are much more predictable than volatile oil prices (IEA, 2021c).

Barriers

There is a lack of supporting fueling and maintenance infrastructure for EV vehicles, such as charging stations on roads or parking. This is a specific challenge for regions with high shares of rural, low-population-density areas (IEA and OECD, 2019). In Latin America and the Caribbean, the deployment of semi-rapid and rapid charging infrastructure has begun, with the highest number of chargers in Mexico and Brazil. Compared to the European Union, North America, or China, the adoption of charging infrastructure is lagging in Latin America and the Caribbean (Quiros-Tortos et al., 2019). Estimates from the United States show that if 50% of sold vehicles are fully electric in 2030, the country needs a network of 1.2 million public and 28 million private chargers, which is 20 times the size of the current network. This translates to a price tag of 35 billion USD (McKinsey, 2022).

Electric cars and buses have higher upfront capital costs, which can be difficult to finance for households and businesses (Lefevre and IDB, 2021). The transition to EVs can erode the tax base for countries that use gasoline and diesel taxes (Cesar et al., 2022). Existing regulations are tailored for fossil fuel transport; for example, government tender for public transport or formulas used to determine ticket prices often assume diesel buses, which effectively prevents EVs from being authorized (Lefevre and IDB, 2021). Household and firms are often unfamiliar with electric technology and lack information, for instance, in terms of fuel usage, maximum range typically needed, cost transparency over the car's life cycle, and the comfort of electric cars (DellaValle and Zubaryeva, 2019; Krogstrup and Oman, 2019). In countries with no current electric fleet, the market size may be too small for car dealers to consider importing EVs without demand stimulation through charging infrastructure uptake and EV investment support. Global used car markets, shipping fossil-based cars to low- and middle-income countries, might slow down the adaption of EVs (IDDRI, 2021a). Finally, fossil fuel subsidies in many countries incentivize internal combustion vehicles (IEA, 2018; Parry et al., 2021) (see previous transformation).

Government interventions

Systematic policy changes are necessary to enable this transformation (OECD, 2021). Infrastructure is needed to enable electrified transport. Governments can plan and build or procure core "backbone" charging fueling networks (e.g., on major highways), and build lanes and parking spaces for zero-emission vehicles (IEA and OECD, 2019). Examples from the European Union show that governments can also incentivize energy companies to build charging infrastructure, for instance, by upgrading existing gas station networks.

Updating government regulations can accelerate EV deployment. Mandates can require a minimum share of cars sold in a defined market to be zero-emission. This causes changes at the level of car sellers and inspires innovation throughout the EV value chain (Wesseling et al., 2015). Additionally, the government can mandate the national public sector to only procure EVs while defining clear goals for private sector adoption over a mid- to long-term timeframe (New Climate Institute, 2020) or set deadlines, such as 2030 or 2035, to stop the sale of new combustion engine cars (IDDRI, 2021b). Creating standardized vehicle fuel labels can improve transparency and information for customers (European Commission et al., 2021).

Financial incentives can improve the attractiveness of EVs. Provision of tailored financial instruments, such as zero interest rate loans, trade-in programs for used gasoline or diesel cars, feebates, and tax exemptions can mitigate the higher upfront cost of EVs. Toll exemptions and tax benefits on car insurance for EVs can also reduce operational costs (Fridstrom, 2019). Governments can use prospective planning to design measures to replace gasoline and diesel taxes with taxes on electricity, car ownership, or use, in a way that ensures that government revenues are not affected significantly by the transition to EVs, and households and firms are better off financially by the transition (IDB, 2021a).

Creating benefits can make EV ownership more convenient or desirable, such as with priority access to lanes and urban zero-emission-vehicle-only zones and times, favorable road pricing for EVs, or an easing of pollution-based speed restrictions (ITF - OECD, 2021).

Transformation 5

Shift freight transport to rail, water, and low- or zero-emission technologies

The transformation

Road freight transport accounts for approximately 7% of global energy-related CO_2 emissions (Kaack et al., 2018). These emissions could rise by 22% by 2050 under current trends (ITF, 2021). In cities such as Bogotá, freight transport is the biggest emission source within the transport sector. Trucks and trains can shift to zero-emission technologies such as battery electric or hydrogen fuel cell drivetrains, depending on the availability of infrastructure and fitness for typical trip length. Water shipping can use batteries for short ranges (e.g., river boats and ferries), while longer-range vessels are projected to use ammonia, methanol, or hydrogen to replace diesel (Davis et al., 2018).

Benefits

Electrification can reduce transportation costs owing to less maintenance, for instance, due to less complex drive trains, and lower energy costs compared to fossil-based alternatives (Hall et al., 2018). Electricity- or hydrogen-fueled freight fleets, especially urban ones due to their proximity to people, can also contribute to improved health both through reduced combustion and reduced brake lining particulate pollution (see Transformation 3). Less road freight transport reduces the investment needed to maintain road infrastructure and decreases accidents and traffic on existing infrastructure.

A long-term move to multi-modal electric freight trains for long-haul freight and battery trucks for short and medium hauling may be cheaper and more effective for countries still developing their freight transport networks. IEA (2021) indicates that battery trucks can be competitive in urban areas with overnight charging infrastructure, and they could be combined with electric trains for multi-modal very-long-distance shipping.

Barriers

The infrastructure necessary to operate zero-emission road freight, such as high-capacity charging and hydrogen refueling networks, is not yet adequately provided (Road Freight Zero et al., 2021). Existing infrastructure often favors roads over rail and water, and investments in inland transport infrastructure are strongly skewed towards road infrastructure at 59% of total investments, followed by rail (30%), air (7%), and sea (4%) (OECD, 2020). For rail and water transport, the lack of rapid and efficient loading systems and services, as well as lacking a connection to local and regional business hubs, create another barrier.

Transport regulations often favor fossil-fuel-based freight (ITF, 2020)—for instance, adhering to security standards targeted at fossil fuel technologies that are not relevant to electrified transport, such as fuel safety compliance. Another example is unambitious or watered down GHG standards. In the United States, replacing GHG standards from the Obama administration with much less ambitious standards in 2020 led to a significant reduction in fuel efficiency requirements (Leard, 2021).

Existing low-carbon technologies provide limited range at a high upfront cost. Due to the lack of sufficient battery capacity, hydrogen infrastructure, and zero-emission transport vehicle supply, long-haul freight transport, especially road transport, is an ongoing challenge for immediate decarbonization efforts (ITF - OECD, 2021). Additionally, little incentive is created for logistic companies to modernize their fleet if emission regulations for trucks are not introduced or enforced (or not fully so), which is the case in Latin America and the Caribbean.

Government interventions

Improving road infrastructure, and specifically recharging/refueling networks, can enable electricity- and hydrogen-fueled multi-modal freight (ICCT et al., 2017). Investing in rail and water transport, especially intermodal connections to enable intermodal transfers, and in infrastructure for rapid loading, and connecting rail and water transport to regional industrial business hubs can expand the network and ease of usage, thereby increasing the attractiveness of alternatives to road freight (Kaack et al., 2018). Electrification of ports and rail infrastructure is another necessary step towards decarbonized freight (ITF-OECD, 2018). In urban areas, upgrading already existing public transport can help to move freight, as done in St. Etienne, France, where trams have been equipped to deliver packages on the last mile instead of cars (TDA, 2018).

Regulatory updates that also support the formalization of the logistics sector can help address zero-emission freight. Options include low-carbon fuel standards, zero-emission vehicle mandates and adoption goals for public and private freight transport, and coordinated phase-out timelines for new fossil fuel trucks (Road Freight Zero et al., 2021). Technical and safety standards need to be updated, such as refueling protocols and standardized refueling nozzles for hydrogen or propagation and electrolyte leakage standards for batteries (ITF - OECD, 2021). Greening the public procurement of freight vehicles can also be considered (Testa et al., 2016). Regulations that incentivize regional supply chains (e.g., in food production) can have a positive impact on the adoption of electric technologies with limited range thanks to shorter transport distances (Inkinen and Hämäläinen, 2020).

Financial incentives can make zero-carbon technologies more attractive. Options include accelerated amortization and tax benefits or subsidies for low- and zero-emission heavy freight vehicles (New Climate Institute, 2020).

Steps can be taken to accelerate the adoption of innovative low-emission technology. This includes the creation of national or regional freight transport strategies, public procurement of innovative technology, and assessments of regional readiness for technology adoption (e.g., determining whether charging systems are in place to allow for electrified transport) (ITF - OECD, 2021). Additionally, initiating regional pilot projects for zero-carbon transport together with the private sector and academia, such as in one project to test high-performance charging in long-distance truck traffic in Germany (German Association of the Automotive Industry, 2021), can accelerate the adoption of technology.

Agriculture, Forestry and Land Use

Agriculture, forestry, and land-use cause 21% of global GHG emissions (Lamb et al., 2021). These emissions are mainly CO_2 from deforestation due to land being used for food production, CH_4 from raising ruminants (mainly beef used for meat and dairy) and rice production, and N_2O emissions from fertilizers (Food and Agriculture Organization [FAO], 2017a). Deforestation itself is mainly driven by beef consumption, as 77% of arable land globally is used directly for beef grazing or indirectly for soybean and other beef feed production (FAOSTAT, 2022). Demand for food in general and animal products in particular is expected to increase by more than 50% and 70% by 2050, respectively, driven by population and income growth globally (Tilman and Clark, 2014). This in turn will lead to a significant increase in direct emissions, deforestation, and biodiversity loss if no transformational action is taken (Searchinger et al., 2019).

In Latin America and the Caribbean, agriculture, forestry, and land-use change (mainly deforestation) represented 46% of all GHG emissions in 2018 (WRI, 2021). Almost one quarter of the terrestrial area in the region is considered protected areas (IUCN, 2021). However, forest cover declined from 53% to 46% of its land area between 1990 and 2020, equaling a destruction of 138 million ha, or half the size of Argentina. The biggest relative decline in coverage at approximately 25–30% has been observed in Paraguay, Guatemala, and Nicaragua (ECLAC, 2021). Between 2013 and 2019, 77% of forest loss was due to commercial agriculture, 25% of which was destined to supply export demand and 75% domestic demand within the region (Dummett, Cassie et al 2021, pg. 24). More than 80% of deforestation in the region was likely illegal in that period (ibid).

Protecting carbon sinks, such as forests and wetlands, also means protecting the rights of indigenous people and groups in the region, who occupy approximately 35-40% of its forests and whose territories account for 14% of the carbon stored in tropical forests globally (FAO and FILAC, 2021). Additionally, the net N_2O and CH_4 emissions per capita from agriculture, while varying, are twice as large as global averages, and land-use changes (mostly deforestation for agriculture or forest growth CO_2) are often over half of the national inventories and much larger than the global average (Bataille et al., 2020). Some of the impact of food on emissions is related to food loss and waste, which is covered under Transformation 15. Lastly, it can be noted that the agricultural sector in Latin America and the Caribbean refers to both small farmers as well as large agribusinesses, which demands that tailormade solutions include both types of farming.

Transformation 6

Promote farming practices that reduce emissions of methane and nitrous oxide

The transformation

Methane from anaerobic decay (e.g., wet rice paddies) and ruminant digestion (e.g., cows) and nitrous oxide emissions from fertilizer decay are responsible for 60% of direct emissions from agriculture, which translates to approximately 10% of the global emissions of GHGs (Searchinger et al., 2019). There are techniques to reduce emissions, such as improving the efficiency of fertilizer use, climate-smart agriculture, and changing the feed provided to ruminants, but they must be learned and applied, and incentives are needed for their application (ibid).

Benefits

Improving fertilizer use efficiency to reduce total fertilizer usage without reducing yields has several benefits; it reduces farmer costs and potentially the need to import fertilizer components. It decreases local soil pollution, as well as water pollution and eutrophication for local and downstream water sources (United Nations Environment Programme [UNEP], 2021a). By improving farm productivity fertilizer, irrigation and land demands can be reduced, the last allowing for less deforestation. This, in turn, can yield positive biodiversity (Mohammad and Adam, 2010; Khaleghi, 2017) and carbon absorption impacts. Capacity building for farmers can enhance farming knowledge and make farmers more resilient towards the impacts of climate change, such as droughts.

Barriers

Farmers often rely on outdated farming practices (Piñeiro et al., 2020). Many farmers are operating in a low-productivity subsistence or otherwise low-productivity mode, and there is a need to strengthen capacities and information to improve farming practices (UNEP, 2021a).

Traditional subsidy schemes, focusing on increasing production and competitiveness, can incentivize overproduction and overuse of intrants, including fertilizers (FAO et al., 2021). Governments globally spend nearly $540 billion per year to support agricultural producers, mostly in the form of subsidies. Government support is effective at improving farmer income and reducing rural poverty, but 87% of that support has been found to be inefficient, inequitable, and to create health risks linked to the agricultural impact on the environment and the impact of unhealthy diets on private health (FAO et al., 2021).

Government interventions

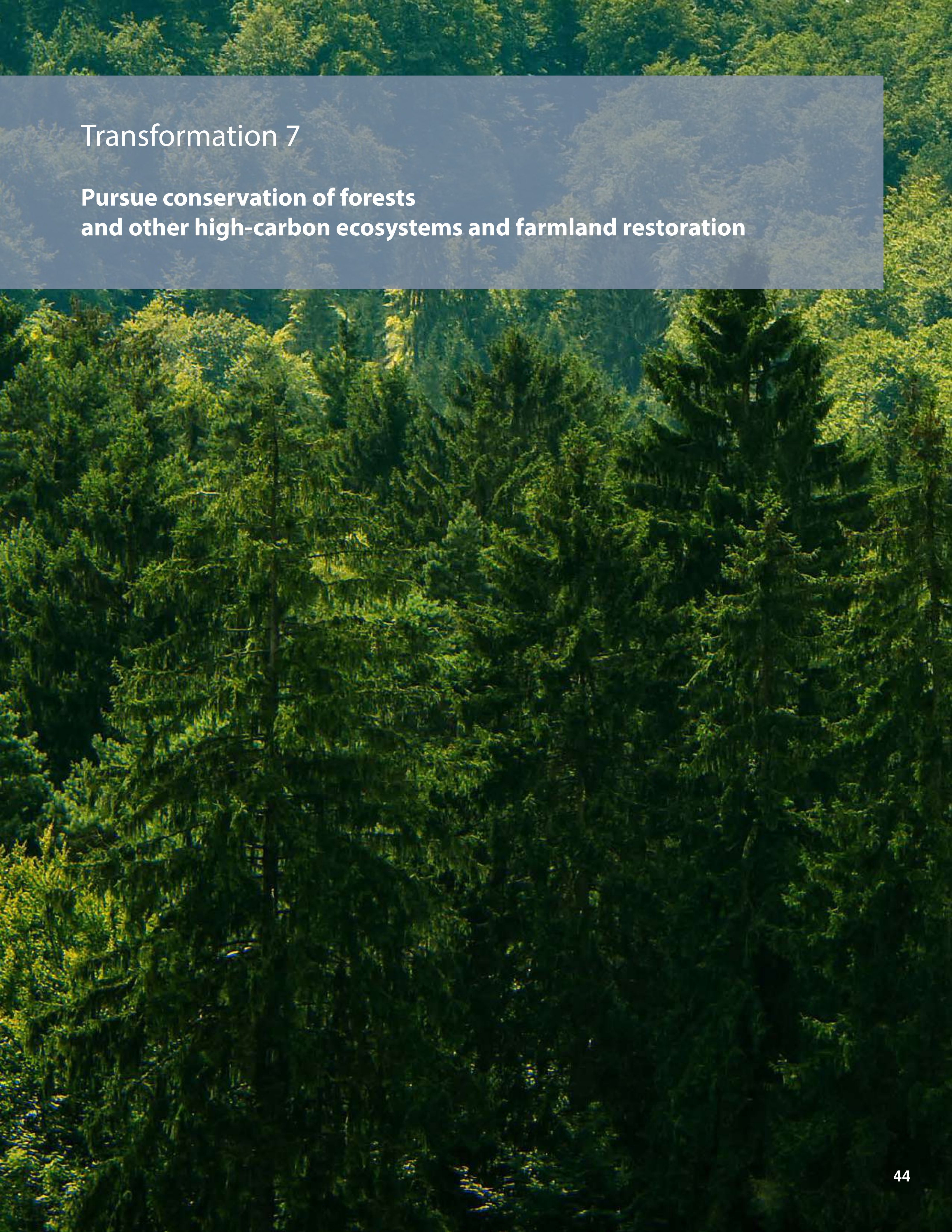
Governments can use agricultural capacity building programs to improve information and capacity of farmers regarding low-GHG emission agricultural practices (Piñeiro et al., 2020). They should also cover techniques to use organic matter to replace synthetic fertilizer and provide expertise in climate-smart agriculture and integrated management of ecological, social, and economic issues to farmers. This often requires farmers having access to education in hybrid farming techniques and animals, as well as other land and crop types and education programs (UNEP, 2021a).

Regulations can support the uptake of low-GHG practices in agriculture, mandate soil quality standards, and help provide targets and roadmaps for fertilizer reduction (UNEP, 2021a). Mandates can establish infrastructure requirements (e.g., install equipment to capture and destroy methane in cow barns). Regulations can also promote rotation cycles for a more balanced use of soil production capacity (FAO, 2017b).

Governments can use financial incentives to promote low-GHG agricultural practices. Policy packages that include financial benefits for farmers show higher adoption rates compared to policies only focusing on environmental improvements (Piñeiro et al., 2020). The government can subsidize technologies such as methane filters, storage and cooling facilities, and farming machinery; moreover, it can integrate subsidies or tax benefits to encourage eco-friendly farming, such as including decentralized electricity generation at the farm using captured methane. Governments can also support research and innovation (e.g., through research grants) to promote locally relevant and effective technologies and good farming practices. Lastly, subsidies for fossil-fuel-based synthetic fertilizers can be gradually reduced and eventually eliminated, while fertilizer made using green hydrogen and low-emission heat can be encouraged (Transformation 13), but this requires paying attention to social and economic impacts and possibly includes using compensation mechanisms.

Transformation 7

Pursue conservation of forests and other high-carbon ecosystems and farmland restoration



The transformation

Conservation efforts preserve natural carbon sinks, and restoration creates additional carbon storage. Medium- to old-growth forests provide large carbon sinks and habitats for biodiversity preservation (FAO and UNEP, 2020). Between 1850 and 2019, carbon sinks reabsorbed approximately 60% of human emissions. Around half of this can be attributed to forests and land, while the other half is absorbed by the oceans (IPCC, 2021). So called nature-based solutions can contribute between 5–12 $GtCO_2eq$ emission reduction by 2030 through protection, restauration, and sustainable management practices. Of this mitigation potential, around 60% are attributed to forests, one fourth to grass- and croplands, one tenth to peatlands and the remainder to coastal and maritime areas (UNEP and IUCN, 2021).

Analyzing countries' NDCs, carbon sinks created by conservation and restoration of forests and farmland restoration are supposed to contribute approximately 25% of total emission reduction by volume (Grassi et al., 2017).

Benefits

Forests like the Amazon are essential to the preservation of biodiversity and play a central role in maintaining functional ecosystems on which most economic activities ultimately rely (IPBES, 2019). Preventing the Amazon from reaching a tipping point (based on a size-related self-generated hydrological cycle), considering carbon storage, erosion mitigation, water supply, and water purification ecosystem services, would safeguard 184.1 billion USD worth of GDP for Brazil (Banerjee et al., 2021). The economic value of forests on a global scale is estimated at 50-150 trillion USD (BCG, 2020). Forest conservation provides many ecosystem benefits, including microclimate temperature moderation, rainfall absorption and flood control during significant weather events, and prevention of irreplaceable soil runoff (Costanza et al., 2014). Studies on soil runoff show that in deforested areas, runoff was approximately 60–100% higher than in comparable areas with forest coverage (Mohammad and Adam, 2010; Khaleghi, 2017). Less soil runoff also contributes to the protection of clean water, and it further contributes to stabilizing regional climates, such as in the Amazon region, and affects productivity, especially in the agricultural sector (IUCN, 2021b). This transformation is also critical to maintaining and increasing habitats for biodiversity conservation (FAO and UNEP, 2020). Active management of protected areas and efforts to encourage multiple uses of standing forests can also allow for the generation of significant income for indigenous and subsistence communities, who are currently managing approximately 28% of globally used land (Garnett et al., 2018).

Barriers

Agricultural expansion caused by increased demand for food is the main cause of deforestation, especially when demand is met with foods that require a large land footprint per unit of calory or protein produced. In Latin America and the Caribbean, approximately 80% of tropical forest deforestation is linked to agriculture expansion (FAO and UNEP, 2020; Dummett, Cassie, et al., 2021). This barrier is discussed further under Transformation 8 below.

Forest land and other high-carbon ecosystems are often not adequately protected, which leads to unpenalized abuse through deforestation for grazing or other agricultural purposes. Land grabbing and speculation, often harming indigenous people who have legal rights to manage about 35-40% of forests, are a main driver of deforestation. Moving cattle to grabbed land and subsequent fencing is a frequently observed way of claiming land titles in areas where previously no formal land titles were established (Dummett, Cassie, et al., 2021). When forests are protected, enforcement is often insufficiently funded (Rochedo et al., 2018). Missing or inadequate management and enforcement of land titles is a compounding challenge (FAO and UNEP, 2020).

Governments often have limited access to information on deforestation, hindering their ability to effectively enforce deforestation prevention (Dummett, Cassie, et al., 2021). In addition, asymmetric information on the monetary benefits of forest areas slows down protection efforts. For instance, governments often have limited capacities to assess the economic benefit of ecosystems, while profit-seeking actors clearly value deforested areas based on wood sold and profit-maximizing agricultural practices.

Many regions suffer from limited fire management capability. Globally, more than 100 million ha of trees (0.2% of the 44bn ha currently covered by tress) are affected by forest fires every year, with more than two thirds burnt in South America and Africa (FAO and UNEP, 2020). In Latin America and the Caribbean, on average 0.36 $GtCO_2$ were emitted by fires between 1997 and 2016, of which more than 90% was attributed to wildfires (Van Der Werf et al., 2017).

Government interventions

Government can update farmland regulations with a stronger focus on conservation to minimize agricultural expansion and slash and burn subsistence agriculture. Similarly, regulation can discourage deforestation for new farm or grazing land (e.g., through payment or taxation for, or prohibition of, deforestation and stronger penalization of unauthorized deforestation). Payment for environmental and ecosystem services, if carefully designed, can discourage deforestation and create other sustainable sources of revenue for local communities (Alpízar et al., 2020) – but they can be difficult to fund.

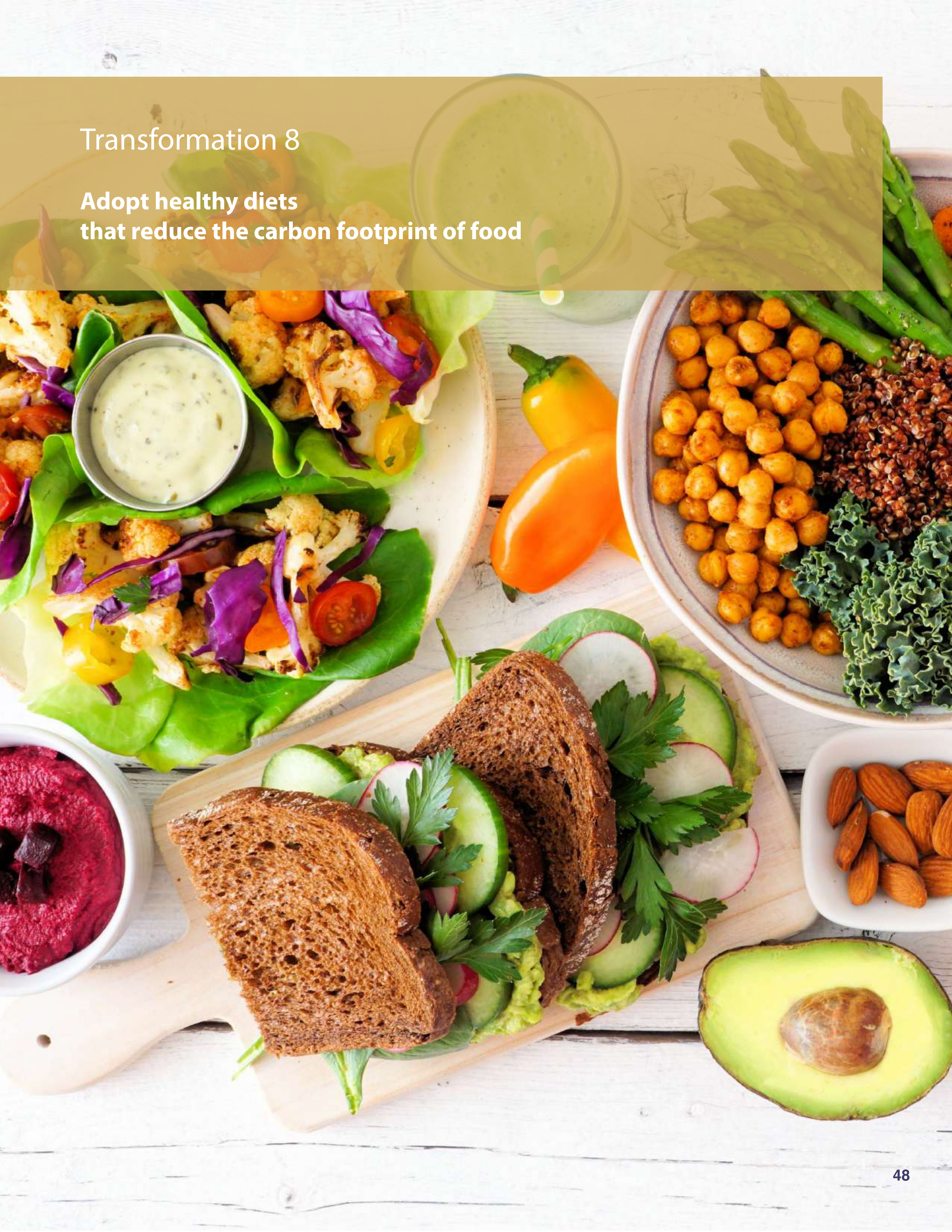
Law enforcement needs to be strengthened (FAO and UNEP, 2020). Depending on the local context and the implementation details, granting land titles to individuals or communities has resulted in mixed outcomes (Blackman et al, 2017). Land title management and enforcement need to be adapted to local conditions, especially in places where indigenous and subsistence communities who use standing forests for income lack formal titles. In Costa Rica, for instance, landowners lacking formal titles can provide other types of proof or use advance payments based on future yield to start the process of obtaining official land titles (FAO and UNEP, 2020). Additionally, certification systems can be put in place to formalize the protection of forests. Governments can also improve the funding of existing protected areas, expand them, or create new ones, essentially diminishing agricultural and extractive activities in these areas (UNEP-WCMC and IUCN, 2020).

Capacity building for farmers can focus on improving yield per unit and increasing and adopting fire risk management practices (FAO, 2009). Governments can also support the creation of capacity for coordinating and aligning agricultural practices, integrated water resource management (e.g., by focusing on water use and water use efficiency), and ecosystem protection and restoration (UNEP, 2021b).

Policies need to be based on a functioning measurement, reporting, and verification system. Governments can increase their monitoring and managing capacity for forests and conservation areas to improve the detection of illegal land-use change and fires. Technology such as drones and software for natural capital management can dramatically reduce MRV costs (FAO, 2018). Fire prevention and management need to be introduced and adequately resourced, including the private sector (FAO and UNEP, 2020). Ideally, local communities can be funded and rewarded for fire management, for instance dead biomass collection can both reduce fire hazard and provide fuel to local communities.

Transformation 8

Adopt healthy diets that reduce the carbon footprint of food



The transformation

Meat and dairy production are the main drivers of GHG emissions within food production. For instance, while maize and wheat cause less than 30 kgCO_2e per kg of protein, beef consumption emits 1,250 kgCO_2e, cow milk 260 kgCO_2e, pork 150 kgCO_2e, and poultry 110 kgCO_2e (Searchinger et al., 2018). Beef and dairy are the main contributors to global deforestation, as they use 77% of arable land globally (Searchinger et al., 2018c). For instance, beef consumption in the United States, while only providing 3% of calorie intake, accounts for approximately 50% of land use and emissions related to food (Searchinger et al., 2019).

In Latin America and the Caribbean, diets are very heterogenous. The region hosts the countries with the highest beef consumption per capita in the world, at triple European averages and 50% above North American averages, as well as countries where poverty translates into food insecurity and inadequate levels of animal protein intake (Dumas and Vogt-Schilb, 2022; IDB, 2019). On average across the region, beef consumption is responsible for 55% emissions from agriculture and 60% of emissions from land-use change, while contributing only 4% of calorie and 12% of protein intake (ibid). At the same time, the prevalence of food insecurity in the region is very high, at more than 75% (Benites-Zapata et al, 2021).

The goal of this transformation is to improve health outcomes by choosing diets that are both nutritious and have a low impact on GHG emissions and land use change. For instance, replacing 50% of meat consumption by other foods globally could lower GHG emissions from production and change in land use by 30% while maintaining or improving nutritional outcomes. Changing to a "no beef or dairy" diet (but still consuming poultry and pork while maintaining total nutrient intake) reduces the pressure on deforestation by 66% compared to the current baseline (Searchinger et al., 2018), and it can further lower water usage and decrease the risk of water scarcity, as the production of animal products accounts for approximately 25% of global freshwater usage (Gerbens-Leenes et al., 2013).

Benefits

Low-meat or plant-based diets can improve health by reducing obesity and serious diseases, such as cardiovascular disease, colorectal cancer, and type-2 diabetes (Battaglia Richi et al., 2015). For instance, a vegetarian diet reduces the relative risk of getting type-2 diabetes by 40% compared to an omnivorous diet in developed occidental countries (Tilman and Clark, 2014). Subsequently, fiscal spending on the health system can be positively influenced by this development. This is especially relevant in Latin America and the Caribbean, where the population is currently not eating a healthy diet, but rather one that is deficient in fruits, vegetables, fiber, and whole grains and excessive in processed and red meats (IDB, 2019).

Plant-based diets reduce the need for water in agriculture, thereby protecting natural water levels and decreasing water scarcity in dry areas. Beef production requires significantly more water, with 15,000 liter/kg of meat compared to 5,874 liter/kg of lentils or 287 liter/kg of potato (Mekonnen and Gerbens-Leenes, 2020). Limiting global diets to 25% animal protein intake would result in water savings of 11–18% (Jalava et al., 2016).

Plant-based diets reduce demand for meat and thus contribute to reducing the need for factory or industrial farming of animals, which is sometimes regarded unethical and inhumane (European Commission, 2021).

Barriers

Agriculture subsidies incentivize the production of meat and dairy. In 2013, OECD countries alone spent $53 billion in livestock subsidies and China $22 billion in pork subsidies (Froggatt et al., 2014). Total global financial support to agricultural producers amounts to $540 billion, with beef and dairy as the most subsidized products, along with rice (FAO, UNDP, and UNEP, 2021).

Lack of information (e.g., through food labelling) skews customer decision-making towards meat and dairy (Shangguan et al., 2019), as consumers are often not aware of the nutrition details and health impacts of different diets (IDB, 2019).

Animal products are strongly integrated into the cultures of most people, in local and regional diet and cuisine (Bryant, 2020), creating a hard-to-change lock-in effect in favor of the consumption of animal products.

Government interventions

The large amount of money dedicated to agricultural subsidies needs to be evaluated and its purpose redefined. Governments need to make sure that transparency over current financial flows is created. Based on this transparency, strategic elements within the agricultural value chain can be defined to contribute to producing lower-footprint foods, including innovation in plant-based diets and promotion of vegetable-focused diets or less-GHG intensive animal meats (FAO, UNDP, and UNEP, 2021).

Governments can use information campaigns and regulations, informed by behavioral sciences and economics, to actively promote the shift to healthier lower-carbon diets. These promotion efforts need to include a focus on creating customer awareness. Food consumption should be placed in a bigger picture—connected to the impacts it has on our daily lives (i.e., economically, socially, and ecologically). Information campaigns (e.g., in supermarkets) could help create this awareness. This includes intuitive food labelling (e.g., by using color coding) for nutrition value and environmental impact (e.g., GHG emissions) (Shangguan et al., 2019).

Regulations can help shift social norms and normalize plant-based or lower-meat diets. This can be done by cutting the procurement of the highest-footprint foods in public kindergartens and schools or designating vegetarian meals or days in office cafeterias (Searchinger et al., 2019). Increasing the comfort of handling and cooking with vegetables (e.g., through a broad dissemination of cooking classes in schools) also contributes to this goal (Fresán et al., 2020).

Financial incentives may contribute to shifting diets. Governments can consider increasing consumer taxes on food products with a high carbon footprint or with specific tolls or taxes at the producer level and reducing taxes on healthier and lower-GHG foods (Searchinger et al., 2019). However, changes in consumer prices are politically difficult, as the experience with fossil fuel subsidies has demonstrated many times (Parry et al., 2021). Thus, it is essential to prepare policies that affect the price of food very carefully by ensuring that consumers understand the reform and agree with it, and that the most impacted actors are compensated (Vogt-Schilb et al., 2019). More generally, governments can assess the impact that support policies have on different foods, and design government support schemes so that they favor the production of items consistent with healthy diets that have a low impact on emissions.

Buildings

Globally, direct emissions from buildings—not taking into account indirect emission due to electricity and heat production—account for 6% of GHG emissions (Lamb, 2021). Indirect emissions from offsite-electricity and heat production increase emissions from buildings to 17% of total GHG emissions (ibid). In Latin America and the Caribbean, buildings account for 5–15% of direct CO_2 emissions (i.e., for space heating and cooking) and half of the electricity used (Bataille et al., 2020; IEA, 2020a). In the region, fossil-fuel emissions in buildings are increasing with the ongoing transition from biofuels to commercial fuels, notwithstanding the substantial indoor air health benefits associated with abandoning traditional biofuels. Embodied emissions in construction materials such as steel and cement are roughly equal to direct combustion emissions (Röck et al., 2020; IEA, 2019a), which are addressed in Transformation 13 below.

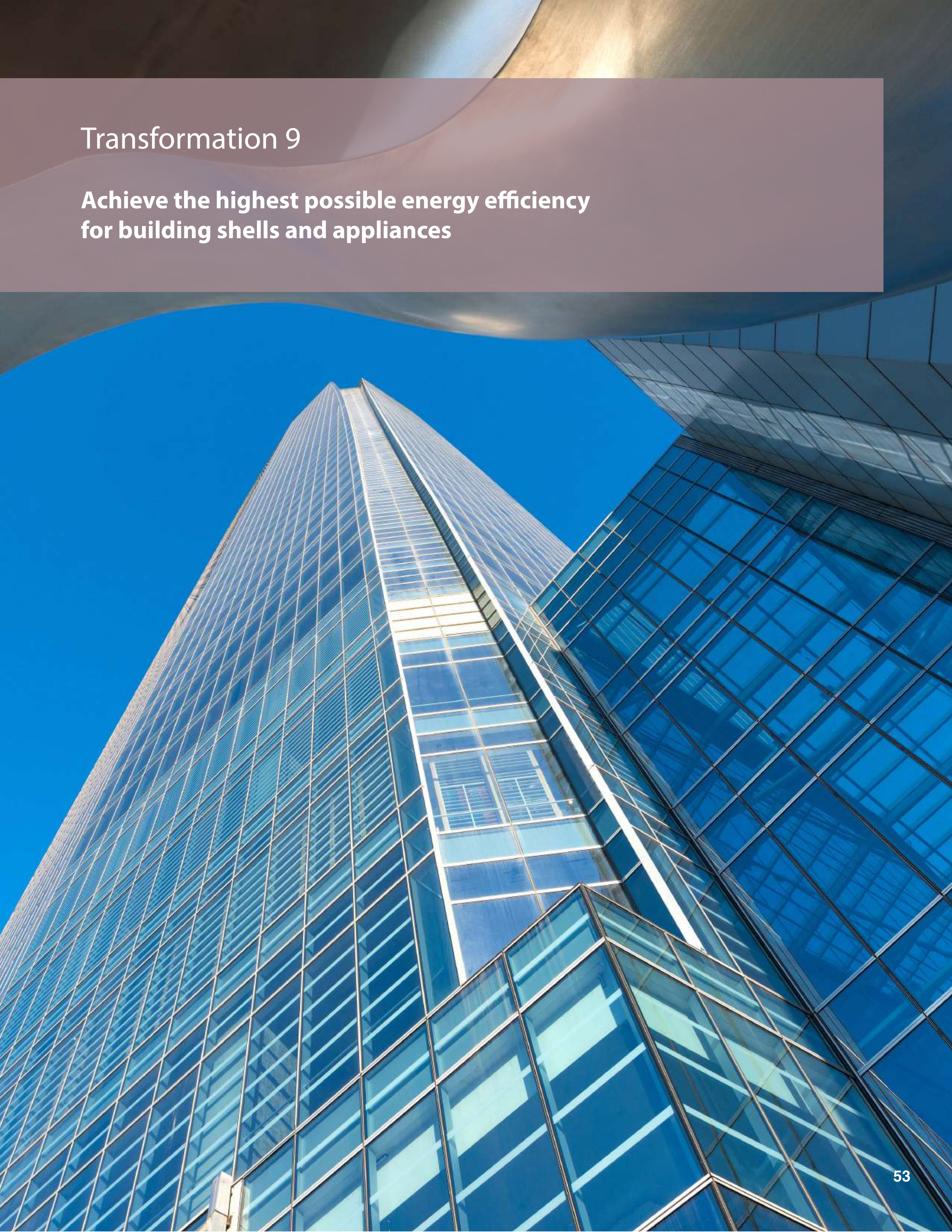
Additional investments required globally to upgrade existing and create new buildings consistent with a two-degree temperature increase limit are estimated at 12 trillion USD by 2050. However, these costs will be more than offset by fuel savings. For Latin America and the Caribbean, fuel savings are estimated to exceed investments by 90 billion USD by 2050 (IEA, 2013b).

All buildings can be seen as integrated systems, with structure, shell, and energy and water components designed to provide a given level of heating, cooling, water delivery, and power to occupants (IEA, 2013a). Transformational systems and shell retrofits are often possible but expensive, and it may sometimes be cheaper to rebuild the building around new low-emissions goals while also improving inhabitant welfare. All interventions to reduce GHGs can benefit from starting with this trade-off in mind.

While exploring Transformations 9, 10, and 11, there is also the demand side of the equation to consider. Rising incomes can lead to demand for larger homes with urban sprawl, which has perhaps evolved to its greatest extent in North America. Full electrification of all new and retrofit transport and high efficiency buildings can offset the GHGs, but energy use will rise and must be supplied. If GHGs are not fully limited for new stock, such as with net-zero carbon regulation by 2030 as suggested in IEA (2021d), the result could be a smaller net reduction in GHGs than what one might expect from supply-side interventions.

Transformation 9

Achieve the highest possible energy efficiency for building shells and appliances



The transformation

Improving energy efficiency in all residential, commercial, and institutional buildings directly reduces the amount of energy of any kind needed and has historically reduced emissions by at least 2% per year for several decades globally (IEA, 2020c). Improving the energy efficiency of buildings is critical to meet climate goals globally because it helps limit the needed production of clean electricity to support electrification (IEA, 2021d; IRENA, 2021). Building renovations will need to be doubled from their current rate of 1% per year to 2% per year, considering that more than 50% of current global building stock will still be standing in 2050 (IEA, 2013b).

The IEA found that to achieve net-zero emissions by 2050 globally, all new construction should be "zero carbon ready" by 2030, and that retrofits need to be carried out on most buildings by 2050 to enable them to meet zero-carbon-ready energy codes (IEA, 2021d). Therefore, this transformation focuses on delivering high-efficiency buildings and appliances.

Benefits

More efficient shells and appliances use less energy and therefore cost less to run and can increase occupant living quality due to moderated temperatures, noise insulation, as well as modernization of appliances and building infrastructure (Ibid; IEA, 2013). In addition, increasing the energy efficiency of buildings decreases the need for investments in additional energy supply and distribution infrastructure (IEA, 2013b).

Barriers

Many factors prevent the uptake of energy efficient buildings (IEA, 2013a, 2020d). More efficient buildings tend to be cheaper to operate over their lifetimes; however, upfront capital costs are higher, and there is a risk of deterioration, destruction, or obsolescence before the extra costs are amortized. The issue of energy consumption can lack salience, as energy bills are often a small part of building value—much lower than the value provided by location and capacity to serve. Distorting subsidies in fossil fuel energy, which amounted to almost 6 trillion USD in 2020 globally (IMF, 2022), blur the real costs of energy and thereby decrease incentives to invest in energy efficiency (Espa and Rolland, 2015). Split agency issues also have a role to play, where rental or leased building renovation costs are imposed on owners, while the savings accrue to the occupant or operator who pay the energy bills. Finally, it's not always clear to building owners and occupants why efficiency is important and why they should expend their limited capital and attention on it. Weak efficiency regulation in building codes and a lack of enforcement of existing regulation decreases the incentive to invest in efficiency actions (IEA, 2017).

Government interventions

The main energy efficiency measure for buildings globally is improving envelope insulation (IEA, 2013a, 2021e). Other energy efficiency measures are related to hot-water production, heating, and cooling systems. Design features such as building orientation to either maximize or avoid exposure to sunlight, window overhang, sizing, roof greening or whitening to absorb heat, natural air circulation to reduce the need for air conditioning, and placement can also contribute to reduced heating, cooling, and lighting loads.

Government regulations can mandate high-efficiency shells for new stock or on-sale properties, announcing targets years in advance—this engages the building supply chain and helps build economies of scale (IEA, 2013a). Governments can also lead, set expectations, and build economies of scale by mandating high-efficiency construction for new government buildings and retrofitting their own building stock (IEA and IMF, 2020).

Governments can use financial incentives to address the higher upfront capital costs of more efficient shells and appliances (Ibid; IEA, 2013), as they can typically borrow capital at one-third the interest cost of households or less, dramatically changing the upfront and amortized capital costs of long-lived projects. They can further provide loan guarantees to private investors to limit the direct fiscal impact. These include loans at subsidized interest rates, renovation subsidies, tax benefits, and pay-as-you-save models. These mechanisms make sense in countries where governments enjoy lower borrowing costs than consumers. Governments may finance such schemes with green or sustainability-linked bonds.

Split incentives issues can be addressed by using financial instruments that tie the borrowed capital repayment to the property instead of current owners, such as through loan amortization repaid through site-specific property taxes (IEA, 2019).

Finally, increasing information and transparency can enable emission savings in buildings. Certification of low- or zero-carbon appliances and buildings can provide transparency to tenants and investors, allowing the enhanced property value to be seen by potential new buyers and renters—who will pay the energy bills. Case studies have shown that providing energy reports to households designed according to behavioral economics insights can incentivize tenants to use energy more sustainably (WRI, 2022a).

Transformation 10

Electrify building appliances

The transformation

All major uses of fossil fuels in buildings can be electrified with existing technology (Williams et al., 2012b, 2021; Bataille et al., 2016; IEA, 2021b; IRENA, 2021). Electrification makes sense even if the grid is currently using fossil fuel for marginal power in the context of a decades-long transition to a net-zero energy system that acts on energy supply and demand in parallel (Audoly et al., 2018). Heating and cooling demand can be met with heat pumps, which are by far the most energy-efficient technology to provide heating, typically consuming 2–4 times less energy than simple electric resistance heating or efficient fossil fuels for the same output, and this modern technology works under a wide range of weather conditions (IEA, 2022b, 2019b, 2020d). Hot-water demand can be fully electrified using a combination of passive solar, heat pumps, and direct resistance heating. Cooking can be done with electric resistance or induction cooktops, or with devices such as electric pressure cookers, even in off-grid locations (World Bank Group et al., 2020). Legacy buildings that rely on fossil gas can be fueled with biomethane until they are replaced or retrofitted.

Benefits

Electrification of space heating and cooking brings energy efficiency gains, as, for instance, heat pumps are 3–4 times more efficient than gas boilers; it further reduces indoor air pollution. For instance, it can help avoid the 173,000–233,000 early deaths that occur due to local air pollution in Latin America, which is mainly linked to the use of biomass (World Bank and IHME, 2016; Statista, 2019). Electrification can also reduce indoor air pollution when used to replace gas stoves. While significantly better overall than traditional biomass, gas stoves release pollutants that can have negative health effects, often exacerbating respiratory conditions such as asthma, especially in children (RMI, 2020).

Finally, the electrification of heating, cooling, and cooking generally leads to lower ongoing energy costs and more stable energy prices, especially once the supply of electricity has largely been converted to wind and solar – see Transformation 1, 2, and 11 (IEA 2020d, 2021d).

Barriers

As with shell and appliance efficiency in Transformation 9, the fundamental challenge is the capital cost of replacing existing fossil-fueled furnaces, hot water systems, and stoves with carbon-free alternatives, and the fact is that most existing buildings were not built to use them (e.g., with sufficiently strong electric wiring and system capacity) (IEA, 2013a; IRENA and China State Grid Co., 2019). A strong increase in demand, as currently witnessed for heat pumps, creates temporary barriers in supply chains and capacity to install appliances. Lack of knowledge of electric options is also a barrier in some markets. Also, heat pumps are more effective in high-efficiency building shells because they provide slow but steady changes in heating and cooling, so shell efficiency should be addressed in parallel (IEA, 2013a) (see Transformation 9). Furthermore, price signals can be counterproductive. In some countries, electricity is taxed more than fossil fuels such as natural gas. Sometimes, natural gas is subsidized or benefits from tax breaks while electricity is taxed. Cultural barriers to changing to electrified appliances can slow down the implementation of this transformation.

Government interventions

Mandates can support electrification of energy uses in buildings (IEA, 2021). Government can ban new methane gas hookups and require electric provision of all services in new buildings, with sufficient panel capacity and wiring (IEA, 2013a, 2021d). The same financial supports (i.e., low-interest loans, subsidies, tax incentives) discussed under Transformation 9 can be applied for the early replacement of fossil-based appliances with electrified appliances such as induction stoves or heat pumps. Again, governments can help build the industry and economies of scale by starting with its own building stock (IEA and IMF, 2020). Pricing reforms can help make electricity more appealing as a fuel than fossil fuel alternatives (Transformations 1 & 2).

Creating customer awareness for the electrification of appliances, their usage, and their benefits through focus group targeted communication, awareness campaigns, and other information action can accelerate the cultural acceptance of electrified appliances.

Transformation 11

Deploy solar electricity and hot water generation on buildings

The transformation

Buildings provide various opportunities to install decentralized solar electricity and hot water generation on rooftops, covered parking lots or, in more innovative settings, walls or windows (IEA, 2021b; IRENA, 2021). This helps to cover the electricity demands created in the building and reduces the need for new transmission upgrades. Solar hot water, which is already common in Latin America, also presents an opportunity for energy storage.

Benefits

While more expensive than utility generation of electricity, building self-generation devices dramatically reduces the need for new transmission lines, which can be challenging to get approval for and site, and can help air-conditioned buildings meet their own peak cooling load, which will grow as climate change progresses. With some storage, it also improves energy security in case of disrupted energy supply. When implemented with smart grid technologies, self-generation can also provide better power dispatch through behind-the-meter or local utility electricity storage and "virtual power line" management, where distributed generation is temporarily stored until transmission is available (IRENA, 2020b,e; IRENA and ILO, 2021).

Barriers

As with shell and appliance efficiency in Transformation 9 and electrification in Transformation 10, the fundamental challenge is the capital cost of installing solar PV and passive thermal hot water generation on buildings as a retrofit, and the fact that most existing buildings were not built to use them (e.g., with sufficient area with sunlight exposure, racking, electric wiring and capacity, plumbing, and the local government and utility approval to do the project (IEA, 2013a; IRENA and China State Grid Co., 2019). Multiple layers of local governance and utility approval for hookup can also hinder the adoption of self-generation; in some extreme cases in early markets in the US, residential solar back-flow overwhelmed the domestic utility system, which was not prepared for the fast uptake. Lack of knowledge of options is also a barrier in some markets, so shell efficiency should be addressed in parallel (IEA, 2013a) (see Transformation 9).

Government interventions

Government interventions need to focus on early capital costs through access to low-interest capital and supporting the formation of an industry to supply self-generation equipment (e.g., through green procurement for government buildings) (IEA and IMF, 2020). Mandates for new builds can support electrification of energy uses in buildings. This has to be complemented, however, by fast-tracked, one-stop local government and utility approval and hookup processes. Government can also ban new methane gas hookups and require electric provision of all services in new buildings (IEA, 2013a, 2021d). The same financial supports (i.e., low-interest loans, subsidies, tax incentives) discussed under Transformation 9 can be applied for the early replacement of fossil-based appliances with electrified appliances such as induction stoves or heat pumps. Again, governments can help build the industry and economies of scale by starting with their own building stock (IEA and IMF, 2020). Pricing reforms can help make electricity more appealing as a fuel than fossil fuel alternatives (Transformations 1 & 2).

Industry

Globally, the industrial sector emits 24% of total CO_2 emissions from fuel combustion and industrial processes (Minx et al., 2021; Lamb et al., 2021). This corresponds to 22% of total GHGs. Industry is composed of many distinct sectors with highly specific chemical processes currently emitting GHGs, such as steel, cement, and chemicals, as well as generic needs for process heat at widely varying temperatures from 50 to 1600 °C and electricity.

Transformation 12

Electrify low heat industry

The transformation

Most industries (e.g., food processing and manufacturing) have moderate heat needs related to processes such as low- or medium-temperature steam, cooking, or pasteurization. These processes can usually be met with temperatures of 150°C or less (Madeddu et al., 2020; Lechtenböhmer et al., 2016). At these temperatures, commercial direct electrothermal, induction, heat pump, direct solar, combined hybrid electric, and solar technologies can provide the necessary heat (Bataille et al., 2018; IEA, 2021d). This transformation focuses on electrifying low heat demand for industry.

Benefits

There are direct energy cost benefits from this transformation if the majority of the electricity comes from cheap modern renewables (Transformation 1 & 2). There are also direct local air quality improvements and their associated health benefits (IEA, 2016). Electrifying low and medium heat can also support the development of a domestic clean industry ecosystem, including clean electricity generation, storage, transmission, and advanced end-uses (IEA, 2021d; Bataille, 2020; Rissman et al., 2020).

Barriers

By far, the largest barrier to clean electrification of low to medium heat industry is the generally relatively high cost of electricity vs. coal, refined petroleum products, or fossil methane in most regions. Of second-order importance, a clean industrial transformation will require relatively more upfront capital and less overtime energy costs, which means financial incentives will be required (IEA, 2021d; Bataille, 2020; Rissman et al., 2020). Finally, information about electric alternatives to currently fossil-fuel-served end-uses can be an issue, especially for small and medium businesses.

Government interventions

Aligning price signals with the electrification goal is key. A key support is the reduction and eventual elimination of fossil fuel subsidies, as recommitted to at COP 26 (Timperley, 2021; IEA, 2022c). In addition, subsidies for industrial fossil fuel consumption need to be gradually removed, which is challenging because of the entrenched users of subsidies (OECD/IEA, 2021).

Financial incentives in the form of tax credits, investment subsidies, or bonified loans can incentivize technological upgrades and transformational innovation investments (IEA, 2021d; Bataille, 2020; Rissman et al., 2020).

Performance standards can support the electrification of industry. In the US, for instance, voluntary energy efficiency commitments by companies under the Better Plants Program are then subsidized with public funds (Fekete et al., 2021).

Governments can also provide better information. Government emissions audits combined with information support programs, as often done for energy efficiency, could help small- and medium-size businesses assess their capacity for electrification and solar heat systems.

Transformation 13

Replace all fuels and feedstocks in heavy, high-heat industry with lower-emissions alternatives

The transformation

Heavy industries such as iron and steel, cement and concrete, and chemicals have specific fuel and feedstock requirements and rely on high-heat industrial processes. These facilities are generally long-lived, with limited opportunities for renovations, and are currently fossil-fuel powered. Bataille et al. (2020) found that 26% of energy and process-related CO_2 emissions in Costa Rica, 37% in Ecuador, 43% in Colombia, 29% in Argentina, 60% in Peru, and 44% in Mexico were linked to industrial processes.

Green hydrogen, defined here as hydrogen produced from electrolysis using clean electricity, will be key to reducing emissions from iron, steel, and chemicals such as ammonia-based fertilizers (Bataille et al., 2018; Bataille, 2020; Philibert, 2017). Hydrogen can replace coal for iron ore reduction in direct reduced iron furnaces, while electric arc furnaces—currently used only for recycling—can combine high-quality low-contamination scrap with new low-GHG primary iron from DRI furnaces.

For cement and concrete, the technical solutions for significant emission reductions are (1) better mixed concrete that minimizes cement use; (2) cementitious material substitution of clinker for fly ash, slags, alkaline wastes, ground limestone, and calcined clays; and eventually (3) CCS (Habert et al., 2020; Scrivener et al., 2018). Hydrogen can also potentially be used as a substitute source for clean high-temperature heat for making cement—perhaps mixed with a slower-burning fuel such as biomass or waste.

More and higher-quality recycling, which has much lower energy use than primary materials, will be key for iron products, aluminum, copper, lithium, and other metals (IEA, 2019a). This is discussed further under Transformation 14 below.

Benefits

This transformation can directly improve local air quality, with direct health benefits, due to reduced combustion of coal, gas, or liquefied petroleum gas (IEA, 2016). The production, storage, and use of hydrogen for industry can be operated synergistically to increase electricity demand flexibility and support firm, on-demand electricity supply (e.g., through mixing with methane in electricity generation turbines and eventually by using fuel cells) (Vogl et al., 2018; Dowling et al., 2020; Neff et al., 2021).

Barriers

A key pathway to lower-GHG steel using existing technologies is the use of recycled instead of primary steel; a key barrier is access to sufficient recycled scrap (IEA, 2021d, 2020d).

One barrier to rapid reductions in cement emissions using existing technologies is the lower degree of professional as opposed to artisanal "bagged" cement and concrete mixing (Habert et al., 2020; Scrivener et al., 2018). Professionally made cement can make maximum use of better aggregate sizing and mixing to minimize cement use in concrete, and tailor cementitious material substitutes to the application.

Another key barrier is the relatively undeveloped nature and high projected costs of some of the key transformative technologies for heavy industries, such as green hydrogen production, direct reduction with hydrogen in metallurgy, and CCS for cement (IEA, 2021d; Bataille, 2020; Rissman et al., 2020; IEA, 2020d). Innovation is, however, moving quickly in some developed countries. Given growing demands for materials, developing countries may be ideal candidates for the early rollout of these technologies once developed.

Another barrier to the eventual use of CCS for clinker making for cement is that facilities were sited next to limestone and not in proximity to geological storage for CO_2.

Government interventions

A key enabling intervention for decarbonizing metals, which is developed further in Transformation 14, is the development of infrastructure for gathering and separating waste metals (e.g., iron, copper, nickel, and trace metals) from electronics of all types. The widespread use of solar PV, batteries, and wind turbines will also eventually require programs to recover the metals in the panels for recycling.

Countries who are able to do so can participate in global industrial technology accelerator programs and potential commercial piloting sites, such as for the replacement of solar photovoltaic-based electrolysis hydrogen in fertilizer production, hydrogen direct reduced iron to electric arc furnace steel, or CCS for cement process emissions (Bataille, 2020; Trollip et al., 2022).

Governments can update building codes to encourage cementitious material substitution, and regulations can be used to enforce professional cement and concrete mixing to the largest extent possible (Habert et al., 2020; Scrivener et al., 2018).

Governments can prefer greener materials in their own procurement for infrastructure and other buildings, as encouraged by the Clean Ministerial Industrial Deep Decarbonization Initiative (UNIDO, 2021) with initial partners of India, Germany, the UK, Canada, and the UAE; if possible, they can also provide an incentive based on GHG intensity for very-low-emission materials (Sartor and Bataille, 2019).

Waste

Emissions from improper management of waste are mainly created at landfills (resulting in 5% of global GHG emissions), within industrial processes such as wastewater treatment and incineration (3.7% of global emissions), and biomass burning in agriculture, forestry and land use (0.5% of global emissions) (Lamb et al., 2021; Liu et al., 2021). In Latin America and the Caribbean, waste represented 6% of GHGs in 2018 (WRI-CAIT, 2021). On a municipal level, waste management is important considering the increasing levels of household material consumption and waste. In Latin America and the Caribbean, 541,000 tons of municipal waste are created daily. This number is expected to increase by 25% by 2050 (Circular Economy Coalition, 2022). Less than 1% of waste is currently composted in the region, and only 4.5% of waste is recycled, while approximately one quarter of waste ends up in open dumps and two thirds in landfills (Kaza et al., 2018). The leading region in recycling, the European Union, recycles approximately 50% of household waste (European Environmental Agency, 2022).

Transformation 14

Work towards a circular economy

The transformation

A shift to a circular economy—that is, an effort to reduce consumption and to reuse, repurpose, repair, or recycle materials at the end of their use lives as much as possible—can dramatically reduce the demand for resources such as plastics, wood products, and metals, as well as the energy for processing new primary materials (IPCC, 2022, Chs. 5 & 11). Since these resources are often generated through energy-intensive and highly polluting processes, such as mining and extraction of new material feedstocks, a more circular economy can thus reduce emissions (IEA, 2021d; Bataille, 2020; Rissman et al., 2020; IEA, 2019a). To implement a circular economy, the priority is to work with manufacturing and building code regulators, architects, and manufacturing and construction firms on how the products of daily life, vehicles, appliances, buildings, and infrastructure are designed, made, and packaged such that they use less resources, last longer, are reusable for other end-uses, and can be easily taken apart and recycled at their end-of-life (Zink and Geyer, 2019; IEA, 2019a).

In terms of increasing product lifespans, both infrastructure and consumer behavior need to be in place to effectively reuse, repurpose, and repair products. Lastly, establishing a glass, plastics (e.g., polyethylene drink bottle), and metals (e.g., aluminum, copper, iron, lithium) gathering and recycling system, both on the commercial and household level, is key to encourage recycling. Alkaline industrial wastes (e.g., fly ash, slags, and masonry) should be channeled to the cement and concrete industry as cementitious material replacements (Habert et al., 2020; Scrivener et al., 2018).

Benefits

The benefits of a circular economy transformation for materials are multifold. Reduction of resource use and extraction reduces local air, water, and land pollution, thereby creating public health benefits; it also reduces the scale of negative land-use environmental impacts that come with resource extraction, such as deforestation or mining. This can have positive impacts on communities living in resource-rich areas and improve living quality and security. Products are designed to be more robust, potentially providing economic benefits to customers (Ekins et al., 2019). Recycled materials such as iron, aluminum, and many other metals are often cheaper because they can dramatically reduce the need for new raw materials and the energy and other inputs needed to process them (Daehn et al., 2017; IEA, 2019a). Recycling also comes with reduced water and transmission requirements, and further cascading impacts, including local air quality. Establishing a circular economy model can also directly create employment, such as focusing on repairing or repurposing products, gathering recyclable materials, and waste management. Circular economy efforts can contribute to establishing new business opportunities and fostering innovation (Kaza et al., 2018). The positive economic impacts at the local, regional, and global level can be worth between low single- to low double-digit GDP points (Ekins et al. 2019).

Barriers

Economic incentives for producers to switch production to circular approaches are low, and high upfront costs and low short-term benefits for transitioning harm the adoption (Ekins et al., 2019). Regulatory incentives to create and sustain a circular economy (e.g., extended producer responsibility laws or regulations prohibiting single-use cups or plastic straws) are largely missing, with the exception of a few countries (Circular Economy Coalition, 2022). Missing end-to-end collection infrastructure and integration into value chains, including the site of industrial and household disposal, the transport of waste to a collection and treatment facility, and the necessary facility to handle waste itself, is a key barrier to establishing a circular economy. Linked to this, behavioral dynamics associated with getting recyclable material to where it can be recycled are currently not prevalent. On a commercial level, dedicated funds for product design innovation are lacking, slowing down the implementation of necessary changes on the product level to integrate them into a circular model. For example, most vehicles at end-of-life are full of copper wiring. If this wiring is left in the vehicles, the copper contamination level of the steel is increased. Beyond certain levels, it cannot be used for thin vehicle sheet steel and eventually cannot be used for structural flat products (Daehn et al., 2017). Lack of readiness for behavioral changes (e.g., when assuming that the quality of new products is better than that of used products) and lack of knowledge and capacity of both customers and the workforce decreases circular economy adoption (Ekins et al., 2019).

Government interventions

Governments can introduce green public procurement policies, including circular economy requirements. In OECD countries, 12% of GDP is linked to public procurement, and approximately 30% of public spending funds public procurement processes. Changing procurement policies can therefore have a significant impact on the adoption of a circular economy (Ekins et al., 2019).

Laws and regulations can create better starting conditions for a circular economy by introducing extended producer responsibility laws. In Chile and Colombia, for instance, the law incentivizes companies to increase the quality of their products, improve collection processes, facilitate the return of products, and support customers in repairing products instead of buying new ones (Circular Economy Coalition, 2022). To reduce waste, regulation can prohibit single-use products (e.g., in take-aways or single-use plastics used for packing).

Governments can both financially and non-financially support businesses in the transition towards a circular economy, such as through price guarantees or capacity building. The municipality of São Paulo buys products with a 30% markup from 160 farmers participating in a project transitioning to a circular economy approach. The farmers further receive technological assistance and capacity building, allowing them to produce organic food and return organic waste to the soil (Ellen MacArthur Foundation, 2022). Companies can be incentivized to increase available funding for circular product design through dedicated public sector support programs, such as investment grants or dedicated research funding for circular economy projects (European Commission, 2020).

Deposit and return systems for all recyclable items have proven to be effective in various historical contexts, especially for glass, aluminum, and polyethylene plastic beverage containers. Deposit and return systems require recyclable waste collection and management centers, which can also serve as a collection point for organics (Transformation 15). It can be mandated that construction waste be trucked to centers where a maximum of these materials can be recovered and recycled. Large fees and penalties for landfill disposal or illegal dumping can be introduced. For household-level waste, municipalities can establish collection points and regular schedules for the pick-up of waste and build waste management facilities that maximize the recycling potential of disposed materials. Behavioral change to incentivize the acceptance of circular economy approaches can be created through knowledge campaigns or financial incentives for correct waste disposal as well as fees for incorrect disposal, such as landfill taxes. These need to must be implemented with caution to avoid adverse effects, such as discouraging material recovery (Callao et al., 2021; Fletcher et al., 2018).

Transformation 15

Reduce food loss and waste and implement active methane management for organic material disposal

The transformation

Organic waste mainly originates from food production, which is one of the most resource-intense industries (Searchinger et al., 2019). While this is difficult to quantify, estimates are that up to 30% of global food production, which amounts to annually 1.3 billion tons, is not consumed but lost before reaching consumers or wasted by end consumers (FAO 2014). This amounts to 28% of global arable land being used for growing food ultimately lost or wasted (WFP, 2021). Approximately 2.2 GtCO_2eq, which is around 4% of global GHG emissions, are tied to food loss and waste (World Wildlife Fund [WWF], 2021). Inefficient market designs, subsidies, and a lack of supply and cooling chains are driving global overproduction (Platform for Accelerating the Circular Economy [PACE], 2021). In addition, only 2% of the organic waste produced in cities is currently reused (Ellen MacArthur Foundation, 2021).

The goal of this transformation is to reduce food losses and waste and improve the methane management of waste that is nevertheless created. Methane can be downgraded to CO_2 through capture and energetic valorization (i.e., combustion to make usable heat and electricity), or it can be avoided using city-scale composting systems (Government of Western Australia, 2022; Climate and Clean Air Coalition, 2022). Methane capture can also be applied to wastewater sewage collection systems, depending on the context (WRI, 2022b).

Benefits

Organic waste reduction and management provide several benefits. Food loss and waste is valued at 1 trillion USD per year; reducing it may thus have a direct economic benefit (WFP, 2021). Land that is currently used for the overproduction of food can instead be dedicated to reforestation or recreation, such as parks and gardens. Improving supply chains and cooling chains can reduce food scarcity and hunger (PACE, 2021; WFP, 2021). Water is saved when overproduction is cut, slowing down aquifer withdrawals, desertification of regions, and overall water scarcity, and water reservoirs such as lakes are less likely to suffer from eutrophication and acidification (WWF, 2021; WFP, 2021). Captured methane can be used to create biogas or biomethane and can be combusted directly for energy (WRI, 2022b).

Barriers

In general, the barriers mentioned in transformations 6–8 such as market failures, meat-based diet choices, and imperfectly-designed government support systems also prevent the reduction of food loss and waste (WWF, 2021). Further, the following specific barriers can be considered. Defective supply and cooling chains as well as wrong pricing incentives cause losses on the producer side and behavioral aspects cause food waste on the consumer side. Many countries and regions do not systematically assess their food loss and waste patterns, thereby losing an opportunity to design fact-based loss and waste management strategies. Binding food loss and waste reduction targets are loosely, if at all, integrated in national policies, regulations, and public procurement processes. Collection systems for organic waste to enable composting are often not in place (PACE, 2021; WWF, 2021). Covering and sealing landfills to capture methane create a net cost, for which financial incentives are lacking.

Government interventions

Supply chain management can be improved by using supply chain software that allows for the timely distribution of goods and reduces food loss caused by extended and uncooled storage (Ellen MacArthur Foundation and Google, 2019). Cooling facilities in several parts of the supply chain (i.e., farms, storage, transport, and markets) can be installed or upgraded. In remote areas, decentralized renewable energy generation can sometimes be used to supply electricity to cooling systems. Public investment grants and subsidies can be considered to support the stakeholders in the supply chain in making these investments. Governments can use their own agencies or cooperate with research institutes to gather systematic information on food loss and waste, helping to design tailor-made strategies for its reduction. They can further establish binding food loss targets to trigger producer-led improvements in the supply chain. This can also include support for local food banks and regulation that promotes the redistribution of surplus food that would otherwise be disposed of. Further, a ban on food waste in landfills can be introduced, mandating composting or other specific treatment of food waste instead. Public procurement can be aligned with food loss and waste targets and food circularity objectives. Municipalities can provide separate collection systems or neighborhood drop off sites for organic wastes. These wastes are then collected at waste management centers for composting or containment and combustion (PACE, 2021; WWF, 2021). Upfront assessment, planning, and capital are required to establish the collection network and processing systems (Center for Clean Air Policy, 2018). Public funds can be made available for the necessary upgrades of waste management centers to capture methane more efficiently or to transform waste into productive goods through anerobic digestion systems (PACE, 2021).

Discussion and conclusion

Meeting the goals of the Paris Agreement is a challenging task. In Latin America and the Caribbean, achieving the Paris Agreement goals would require realigning 7% to 19% of GDP, equaling up to 1.3 trillion USD worth of private and public spending, every year (Galindo Paliza et al., 2022). This is not a net cost: climate action would not only be much cheaper than the costs of inaction but would also bring substantial benefits. To reiterate, climate action is mainly not about spending more; it is about spending differently. This paper suggests that there are many effective and politically feasible actions available to governments for redirecting spending and making progress towards achieving net-zero emissions.

One challenge will be to prioritize and coordinate government interventions across sectors and over different levels of government (from the local to the federal). Two instruments created under the Paris Agreement may provide governments with a tool do so. The first is NDCs, a public national commitment to reduce emissions and adapt to climate change, often over the medium term. The second instrument is LTS, which provide aspirational roadmaps towards a low-emission development by 2050.

NDCs and LTS provide a venue for national governments to gather government officials, academic, private sector representative, and ordinary citizens and discuss how the country can translate a long-term net-zero emission goal into a series of changes that need to happen in all sectors over time (Jaramillo and Saavedra, 2021). From there, the focus of the policy discussion can move to understanding barriers to change and designing government interventions to enable decarbonization by lifting them. Many countries around the world have chosen to use long-term climate strategies in this fashion (UNFCCC, 2022). For instance, Costa Rica's decarbonization strategy establishes what sectoral transformations, organized over 10 lines of action, will allow the country to reach net-zero emissions by 2050, and then provides more than 70 government interventions for 35 government agencies to be implemented by 2023, 2030 and 2050 (Government of Costa Rica, 2019). In addition to serving as a roadmap for government interventions to redirect domestic financial flows, the government was able to use the strategy to attract financing from international financial institutions such as the Inter-American Development Bank and the French Development Agency (Delgado et al., 2021, box 1).

Many different stakeholders have a role to play in enabling the transition. In this paper, we mainly focus on the role of so-called line ministries, public companies, and public regulators. Other publications provide insights on the roles that transversal ministries can play (e.g., Cárdenas et al., 2021; Delgado et al., 2021). For instance, Delgado et al. (2021)

detail how ministries of finance and planning can establish a strategy to finance the transition and ensure that public spending and the fiscal strategy support the implementation of sector transformations consistent with a transition to net-zero emissions. Similarly, Bhattacharya et al. (2019) provide insights on making sure that public infrastructure projects are systematically designed with climate change and broader sustainability goals in mind from the onset. Further work could focus on the respective roles of different levels of government, such as national, regional, and municipal governments, which are likely to depend on local institutions. Institutional and governance changes may themselves be required to remove profound barriers to decarbonization—these are also left for future work.

Moreover, for the transition to net-zero emissions to contribute to social development goals and be politically acceptable, it must be just and inclusive (Vogt-Schilb and Hallegatte, 2017). A just transition means that governments should aim to maximize the socioeconomic benefits of the transition, anticipate and compensate losses and transition costs, and consult all stakeholders when designing climate policy. Other work has shown that social ministries can play a key role in making that happen (e.g., ILO, 2018; Saget et al., 2020). For instance, they can ensure that social protection cushions consumers from negative impacts of climate policy, the education system provides the skills that workers need to practice green jobs, and labor regulation sets decent working conditions for new occupations.

Finally, while this work focuses on incremental government interventions to enable the transition to net-zero emissions, more profound barriers can hamper the transition. For instance, a failing banking system could make it much more difficult for the private sector to invest in any solution with higher upfront costs. A broken education system can imprison households in poverty and deny them the skills required to participate in a green economy. While the transition to net-zero may provide an opportunity for pursuing inclusive green growth, it does not remove the need to pursue transversal development policies.

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Getting to net-zero emissions is necessary to limit global warming to well under 2 °C and towards 1.5 °C, which are the temperature goals of the Paris Agreement. More than 50 countries globally have set targets to reach net-zero emissions, typically by 2050, and most others are working on similar goals. Achieving these targets requires transformations in the electricity, transport, agriculture, land-use, buildings, industry, and waste-management sectors. While solutions exist to transition to a carbon-neutral economy, including both technology and behavioral changes, which often come with economic, social, or development benefits, many barriers prevent their uptake. We compile evidence from the academic and gray literature to identify 15 sectoral transformations that allow the achievement of net-zero greenhouse gas emissions. We then list barriers that prevent their uptake, such as hurdles related to infrastructure, regulations, public and private finances, information, and political economy issues. Finally, we provide more than 50 examples of sector-level government interventions that can lift these barriers, such as building infrastructure, reforming regulations and subsidies, providing information and capacity building, and managing distributional impacts. Governments can use this information to inform the design of comprehensive climate strategies that translate the long-term net-zero emission goal into a roadmap of required transformations in each sector, and then work on designing and implementing government interventions at the national, regional, or local levels to enable them.