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Resource consumption and production policies for sustainable cities

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Contents

1 Introduction

Urbanisation creates challenges and opportunities to achieve economic growth, sustainable use of natural resources and resilient cities. Careful assessment of potential impacts of new policies, adequate monitoring of past decisions, and citizens' participation are essential for achieving sustainable development. Policies to reconfigure the form and functions of cities, transition to renewable energy use, improve use and conservation of water resources, adequate management of waste flows could contribute to a more environmentally friendly use of resources that could support economic growth. However, policies and actions targeting only specific components of the urban fabric are likely to miss on opportunities and potentially result in cost inefficiencies. A transformative and integrated approach is needed to achieve significant improvements in the welfare of urban dwellers while reducing resource use and environmental impacts (Swilling et al., 2018). Therefore, urban resource policies should combine objectives into policy mixes and rely on multiple instruments to address underlying drivers of unsustainable use of urban materials, energy, land and water (Hirschnitz-Garbers et al., 2016).

Public participation is key for successful and sustained transformations towards urban resource use efficiency. Strengthening and developing community participation, knowledge and networks are strategic for successful policy implementation (Weible et al., 2012). Regular stakeholder engagements in policy reviews could improve awareness, information sharing and policy buy-in (UNEP, 2011). An emerging component of policy mixes is targeting consumer behaviour, which can help increase the feasibility of profound behavioural changes in the long term. Such an approach is based on behavioural science concepts such as nudge, which has been increasingly recognized to help policy makers in different countries to integrate behavioural insights into policy design and implementation (Lehner et al., 2016).

Based on a review of urban resource use policies, strategies and instruments in peer-reviewed papers and reports from multiple governmental and international agencies, we compiled a list of policy alternatives and examples to inform the discussion of pathways to sustainable resource consumption in cities.

2 Resource use policy

This section includes examples of resource use policy and interventions organised around key broad areas for action: energy use, transportation, material consumption and waste, water, and land use. Such policies include a combination of regulatory instruments, economic incentives, voluntary action, dissemination of information to build community capacity, and mechanisms to support voluntary actions towards sustainable resource use. Regulatory instruments include the determination of environmental or technical standards, restrictions or bans. Economic incentives include internalising social costs through taxes and use charges; facilitating adoptions of cleaner or improved resource-efficient technologies/practices through subsidies, soft loans, and tax reductions; tradable permits for extracting resources or emitting pollutants to certain amounts; and deposit-refund schemes for promoting recycling practices (Bengtsson et al., 2010). Voluntary actions include unilateral commitments made by polluters; private agreements to reduce environmental impacts; environmental agreements between industry and public authorities; voluntary programs promoted by public authorities to achieve specific goals (OECD, 2003). We indicate links between Sustainable Development Goals (SDG) indicators and each listed policy but highlight that some actions could have implications for additional SDGs. An expanded description of the listed SDG indicators is presented in Appendix A.

2.1 Energy

Cities consume around 70% of global energy and account for around 73% of fossil fuel CO_2 emissions (Güneralp et al., 2017). In an analysis of data from 271 cities, Creutzig et al. (2015b) found that economic activity, transport costs, geographic factors, and urban form explain 37% of urban direct energy use and 88% of urban transport energy use. The design of urban areas is a key determinant of operational and embodied energy use. However, trade-offs of different urban forms should be assessed to identify cost-effective pathways towards sustainable energy use in urban areas. For instance, compact cities can help reduce energy use for transportation, and urban intensification requires large amounts of embodied energy in buildings and other infrastructure (Rickwood et al., 2008). Hilman and Ramaswami (2010) estimated that transboundary emissions in eight U.S. cities include “buildings/facilities energy use (47.1%), regional surface transport (20.8%), food production (14.7%), transport fuel production (6.4%), airline transport (4.8%), long-distance freight trucking (2.8%), cement production (2.2%), and water/wastewater/waste processing (1.3%)”. While the percentages are expected to vary across regions, this information could help identify areas where energy interventions could have a larger impact on total energy use and emissions.

Energy efficiency improvements

Policy	Description	SDG indicator	Environmental improvement	Examples
Transition to renewable energy	Incentives and contracting arrangements to increase the share of renewable energy in the city's energy supply.	7.2.1 Renewable energy 9.4.1 CO_2 emissions per unit value-added 11.6.2 Urban air pollution	Reduce fossil fuel use, GHG emissions and air pollution.	The Australian Capital Territory (ACT) transitioned to 100% renewable electricity use in 2020. The ACT government secured 10-20 year contracts through reverse auctions for wind and solar energy provision. Emission reductions associated with such transition helped the city achieve 40% emissions reduction by 2020[1] relative to 1990 levels. The Netherlands' government waives energy tax surcharges for energy sourced from sustainable sources such as renewables, landfill gas, biogas, or sewage gas that people produce by themselves [2].
Retrofitting buildings	Upgrading building components to improve their thermal performance and aesthetics or adapt them for alternative uses. Retrofitting older buildings could help reduce energy demand for cooling and heating.	7.2.1 Renewable energy 7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.6.1 Solid waste management 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 12.2.2 Domestic material consumption 12.5.1 Recycling rates	Reduce energy demand, GHG emission, air pollution and material use.	Offsetting the environmental impacts of new buildings could take up to 80 years. In contrast, retrofitting buildings could reduce energy demand in a cost-effective way[3]. Upgrades to government-owned or managed buildings could expedite the transition to more efficient built environments create jobs and economic growth. For instance, Seoul is targeting the installation of solar panels on all municipal buildings and a million homes by 2022. As of 2021, the city had installed around 98MW of solar energy systems on municipal buildings, and more than 13,000 homes had received solar panels. In addition to energy savings, this action reduced PM2.5 pollution by around 8.7 tonnes[4]. Upgrading social housing could also contribute to reducing energy poverty. Many cities have also implemented incentives (e.g. low-rate loans or subsidies) for lightning retrofitting and replacing energy-inefficient appliances. Targeted building upgrades could result in significant environmental improvements. A study in Cambridge, Massachusetts, suggests that retrofitting 16% of the urban buildings could reduce 40% of the city's GHG emissions[5].

[1] https://www.environment.act.gov.au/energy/cleaner-energy#:~:text=a%20new%20window.-,The%20ACT's%20100%25%20renewable%20electricity%20target,its%20electricity%20from%20renewable%20generators.&text=It%20delivers%20nearly%20all%20of,on%201990%20levels%20by%202020.

[2] https://business.gov.nl/regulation/energy-tax/

[3] https://www.lendlease.com/better-places/20170317-refitting-old-buildings/

[4] https://www.c40knowledgehub.org/s/article/How-cities-can-strengthen-local-economic-recovery-by-investing-in-building-retrofits?language=en_US

[5] https://energy.mit.edu/news/how-make-cities-more-energy-efficient/

Policy	Description	SDG indicator	Environmental improvement	Examples
Information to improve the energy performance of buildings	Providing information, equipment, and technical advice to enable assessments of the energy performance of buildings. This can help target incentives to improve building components to reduce energy use.	7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 12.2.2 Domestic material consumption	Reduce energy use, GHG emissions and air pollution	The government provides free energy assessments through phone, online, and onsite mechanisms in the Australian Capital Territory. Users receive information about building components that could be improved and their potential energy savings to inform decisions[6].
Incentives for high-performance buildings	Rating systems measure the environmental performance of buildings. This approach helps reduce energy consumption by promoting the use of building technologies such as skylights, double glazing windows and solar panels. Incentives could also be used to encourage the use of low-carbon materials in buildings.	7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 12.2.2 Domestic material consumption	Reduce GHG emissions, water pollution and water and material consumption. Improve waste management.	There are multiple international building ratings that allow entities to certify their efforts towards sustainable provision of building space e.g. LEED Certification (the U.S. and Canada)[7], Green Star[8] and NABERS[9] (Australia), BEAM Plus (Hong Kong) [10].
Strengthening energy efficiency requirements	Setting and enforcing efficient sustainability standards for new constructions and office and household appliances.	7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 12.2.2 Domestic material consumption	Reduce energy consumption and related environmental impacts.	Utilities in the U.S. spent around $8 billion on energy efficiency programs saving around 27 million MWh of electricity. Such energy savings help utilities avoid costly investments in new power generation[11].
Waste to energy conversion	Some municipal waste can be used for biofuel generation. For instance, waste oil or fat from kitchens can be recycled to make biodiesel, and food waste could be used to generate biogas.	7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 12.5.1 Recycling rates	Reduce fossil fuel use, GHG emission, air pollution, waste generation, and protect water resources from waste pollution.	In Brazil, Biotechnos reuse residual kitchen fats to produce biofuels. It has generated around 1500 jobs and produces around 30,000 litres of biofuel per day, which help offset around 80 tonnes of carbon dioxide equivalent and protect around 750,000 cubic meters of drinking water[12].
Incentives for PV installation	Incentives and rebates for encouraging households or businesses to install solar power generation and storage devices.	7.2.1 Renewable energy 7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.6.2 Urban air pollution 12.2.1 Material footprint 12.2.2 Domestic material consumption	Reduce fossil fuel use, GHG emissions and air pollution.	In Kasese, Uganda, a web-based application helps evaluate potential electricity generation from rooftop solar photovoltaics (PV) allowed evaluation of the costs of incentives, affordability, and the total volume of investments to deploy solar energy systems.

[6] https://www.actsmart.act.gov.au/what-can-i-do/homes/energy-service
[7] https://www.usgbc.org/about/mission-vision
[8] https://new.gbca.org.au/green-star/exploring-green-star/
[9] https://www.nabers.gov.au/about
[10] https://www.hkgbc.org.hk/eng/beam-plus/beam-plus-new-buildings/index.jsp
[11] https://www.aceee.org/research-report/u1808
[12] https://unfccc.int/climate-action/momentum-for-change/women-for-results/bioplanet-programme

2.2 Urban transportation

Inefficient transportation infrastructure and slow renewal of urban vehicles reduce mobility and increase vehicle costs, pollution, and driver stress. Such impacts cost around $120 billion per year in the U.S. with comparable estimates in other regions[13]. In Australia, traffic costs in 2015 were estimated at $6 billion in private time, $8 billion in business time, $1.5 billion in additional vehicle operating costs and $1 billion in additional air pollution costs[14]. In addition, the materials required for urban transportation infrastructure creates significant environmental pressures (Nguyen et al., 2019). A range of instruments and policies have been implemented worldwide to reduce road traffic and its associated impacts on air pollution, congestion, noise, and waste. These include reducing or banning traffic in certain areas, enhancing, and promoting public transportation, transitioning to renewable fuels, facilitating car-sharing schemes.

Policy	Description	SDG indicator	Environmental improvement	Examples
Congestion charges	A fee is charged per motor vehicle driven within an area.	8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.2.1 Public transport access 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 13.2.2 Total greenhouse gas emissions per year	Decrease emissions, pollution, and energy use.	A congestion charge in central London decreased daily vehicle trips by around 70,000 (UNEP, 2011), CO_2 emissions by 20%, and NO_X and PM_{10} emissions by 12% (Beevers & Carslaw, 2005b). Bus use increased, and emissions from buses were offset by improving the environmental performance of the bus fleet (Beevers & Carslaw, 2005a)
Electronic road pricing and vehicle quota systems	Toll charges according to time and congestion levels to manage traffic.	8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.2.1 Public transport access 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 13.2.2 Total greenhouse gas emissions per year	Decrease emissions, pollution, and energy use.	Estimates for Singapore indicate that vehicle quotas could reduce between 6% to 40% car ownership depending on the cost of the certificate of entitlement (Song et al., 2019b).
Infrastructure development	Proximity to public transportation infrastructure has a direct effect on car ownership. Improving public transportation, road networks, and bike/pedestrian pathways reduces the environmental footprint of urban transportation.	8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.2.1 Public transport access 11.3.1 Sustainable urbanization rates 11.3.2 Urban planning management 11.3.1 Sustainable urbanization rates 11.3.2 Urban planning management 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 13.2.2 Total greenhouse gas emissions per year	Decrease emissions, pollution, and energy use.	In Singapore, an overall 10% reduction in distance to a rail train station generates a 1.22% reduction in car ownership (Song et al., 2019a). Proximity to expressway exits does not show a significant impact on car ownership in Singapore (Song et al., 2019a). Bogota's rapid transit bus system has reduced the city's greenhouse gas emissions by around 40%[15], around 14% drop in travel emissions per passenger (UNEP, 2011). This system has been replicated in several cities worldwide.
Car-sharing, ride-sharing schemes	Promotion of short-term car rental.	8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.2.1 Public transport access 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 13.2.2 Total greenhouse gas emissions per year	Reduce car dependency, congestion, emissions and pollution, and material consumption associated with ownership of private vehicles	The use of shared electric vehicles in Lisbon, Portugal, could decrease energy consumption up to 47% and CO_2 emissions by 65% (Baptista et al., 2015). A study of 1,500 Australian households suggests that the impact on car ownership of access to car-sharing schemes may be marginal (Zhou et al., 2020).

[13] https://www.vtpi.org/tdm/tdm96.htm
[14] https://soe.environment.gov.au/theme/built-environment/topic/2016/increased-traffic#built-environment-5443
[15] https://ideas.ted.com/these-cities-around-the-world-are-focusing-on-biking-and-walking-instead-of-cars/

Policy	Description	SDG indicator	Environmental improvement	Examples
Promoting daily active travelling	Urban design enables urban dwellers to access services by foot or bike e.g. "15 minutes cities"[16] or "complete neighbourhoods[17]. Developing sustainable and walkable communities while promoting mass transit such as trains and buses and non-motorised travels like walking and bicycling.	8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.2.1 Public transport access 11.3.1 Sustainable urbanization rates 11.3.2 Urban planning management 11.3.1 Sustainable urbanization rates 11.3.2 Urban planning management 11.6.2 Urban air pollution 11.A.1 Urban and regional planning 12.2.1 Material footprint 13.2.2 Total greenhouse gas emissions per year	Reduce car dependency, congestion, emissions and pollution, and material consumption associated with ownership of private vehicles.	A study of 4,000 people living in London, Antwerp, Barcelona, Vienna, Orebro, Rome and Zurich indicates that people who biked daily had 84% fewer carbon emissions from travel than non-cyclists (Brand et al., 2021). Bike-sharing schemes replace mainly walking trips rather than car trips (Bullock et al., 2017). The net effect of bike-sharing on emissions needs to account for the fuel consumed by bike-share operators' vehicles (Fishman et al., 2014).

2.3 Materials and waste

The demand for materials to produce, operate, replace, and expand the built environment and cover the consumption demand of urban dwellers poses significant pressure on the environment. Urbanisation dynamics and improvements in economic and wellbeing indicators are expected to increase resource consumption in cities. In 2010, cities accounted for around 60% of global material consumption (Swilling et al., 2018). By 2050, urban areas are projected to consume around 90 billion tonnes of materials (Baynes & Musango, 2018). Improvements in resource consumption require coordinated action across multiple components of the urban fabric, from the restructuring of the urban form to changes in household consumption patterns (Swilling et al., 2018).

Policy	Description	SDG indicator	Environmental improvement	Examples
Deconstruction, recyclability, and Design for Disassembly (DfD)	Deconstruction is the process of dismantling a building so that materials can be salvaged for recycling or reuse.	7.3.1 Energy efficiency 8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.6.1 Solid waste management 12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.5.1 National recycling rate, tons of material recycled 13.2.2 Total greenhouse gas emissions per year	Reduce embodied GHG emissions. Decrease demolition waste.	In the Netherlands, over 80% of construction and demolition waste is recycled, mainly as a sub-base for roads. It is prohibited to dump reusable building waste. Designing buildings for deconstruction at the end of their life could reduce waste (Rios et al., 2015).
Compost rebate programmes	The programme provides incentives to residents to start composting to reduce waste going to landfills and make purchasing organic recycling systems easier.	6.3.2 Ambient water quality 6.6.1 Protect and restore water-related ecosystems 9.4.1 CO_2 emissions per unit value-added 11.6.1 Solid waste management 12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.3.1 Global food loss 13.2.2 Total greenhouse gas emissions per year	Reduce waste going to landfills, improve water quality, save energy use in waste disposal equipment.	Several cities have composting rebate programmes to reduce household food waste going to landfills. Such programs include subsidising the purchase of composting equipment and disseminating information through traditional or online media, e.g. City of Brisbane[18], Baw Baw Shrine[19].

[16] https://www.15minutecity.com/
[17] https://www.completeneighborhoods.org/
[18] https://www.brisbane.qld.gov.au/clean-and-green/green-home-and-community/sustainable-gardening/compost-and-food-waste-recycling/compost-rebate-program
[19] https://www.bawbawshire.vic.gov.au/Resident-Information/Environment-Recycling-and-Waste/Environmental-Grants-and-Rebates

Policy	Description	SDG indicator	Environmental improvement	Examples
Single-use plastic charge	Charges for single-use plastic bags in retail transactions.	6.3.2 Ambient water quality 6.6.1 Protect and restore water-related ecosystems 8.4.1 Material footprint 12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.5.1 Recycling rates	Reduce waste going to landfills, material consumption for producing plastic, GHG emissions and water pollution	In England, each single-use plastic bag taken from large stores is charged. In 2020, plastic bags sales fell by more than 95% relative to 2016 sales. In 2014, per capita bag purchase was around 140 bags per year. By 2020 this number had dropped to 4 bags per year (Thomas et al., 2019).
Electronic waste recycling scheme	When electronic waste is dumped in landfills, some components like lead, mercury, cadmium, and arsenic can leach into soil and groundwater, harming human health and the environment. Providing e-waste collection services can help reduce e-waste in landfills.	12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.5.1 Recycling rates	Reduce hazardous waste in landfills and water pollution. Recycle material required for electronics.	The Australian Television and Computer Recycling Scheme provides Australian households and small businesses with free access to industry-funded collection and recycling services[20].
Capacity building on waste separation and recycling	Developing knowledge and engaging communities towards efficient waste management.	6.3.2 Ambient water quality 6.6.1 Protect and restore water-related ecosystems 9.4.1 CO_2 emissions per unit value-added 11.6.1 Solid waste management 12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.5.1 Recycling rates 13.2.2 Total greenhouse gas emissions per year	Reduce waste going to landfills, GHG emissions and air and water pollution. Reduce material demand.	Toyama city, Japan, implements strategies to educate school children and local businesses on waste separation and recycling. The city has several local recycling facilities for different materials and stages [21].
Volume-based waste fee	Economic incentives for people to dispose of less waste and encourage recycling	6.3.2 Ambient water quality 6.6.1 Protect and restore water-related ecosystems 9.4.1 CO_2 emissions per unit value-added 11.6.1 Solid waste management 12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.5.1 Recycling rates 13.2.2 Total greenhouse gas emissions per year	Reduce waste generation and material consumption.	Since 1995, the South Korean Government has implemented the Volume-Based Waste Fee (VBWF) for garbage disposal with the goals of reducing wastes and encouraging recycling [22].
Waste charges for materials difficult to recycle and harmful to humans and the environment	Fees to reduce the use and waste of hazardous materials or products challenging to recycle.	6.3.2 Ambient water quality 6.6.1 Protect and restore water-related ecosystems 9.4.1 CO_2 emissions per unit value-added 11.6.1 Solid waste management 12.2.1 Material footprint 12.2.2 Domestic Material Consumption 12.4.2 Hazardous waste generation 12.5.1 Recycling rates 13.2.2 Total greenhouse gas emissions per year	Reduce waste generation; reduce toxic waste generation; reduce material consumption and protect water resources.	The South Korean Waste Disposal Charge System charges manufacturers and importers for disposing of goods/materials/containers that are difficult to recycle and for managing harmful substances e.g. pesticides and toxic products, disposable diapers, cigarettes[23].

[20] https://www.awe.gov.au/environment/protection/waste/consumers/recycling-drop-off; https://www.recyclingnearyou.com.au/computers; www.racgp.org.au%2Fdownload%2FDocuments%2Fe-health%2Fe-waste-solutions.pdf
[21] https://resilientcitiesnetwork.org/downloadable_resources/UR/UO/case-study-toyama-02-.pdf
[22] https://www.greengrowthknowledge.org/national-documents/two-decades-effect-volume-based-waste-fee-system-south-korea
[23] https://www.keco.or.kr/en/core/operation_waste/contentsid/1979/index.do

2.4 Water use

Sustainable urban water supply depends on the conditions of a city's water sources and the infrastructure for cleaning, storing, and distributing such a resource. When the water supply is insufficient, community adaptation measures are needed to reduce resource use or increase water supply (Krueger et al., 2019). For instance, green roofs, rainwater harvesting, and local water storage could increase urban water supply. Water recycling and reuse also contribute to increasing water productivity, and the process is supported by source separation of wastewater to facilitate its treatment (Hoekstra et al., 2018).

Policy	Description	SDG indicator	Environmental improvement	Examples
Low impact development (LID): Promoting stormwater infrastructures such as bioretention ponds, bioswales, rain gardens, green roofs, and permeable pavements	LID is a site design approach that helps manage stormwater runoff using green living infrastructure. It provides habitats, flood protection, cleaner air, and cleaner water. LID is the term used in the U.S. and Canada while it is called water sensitive urban design (WSUD) in Australia; and Sustainable drainage systems (SuDS) in the U.K.	6.3.2 Ambient water quality 6.4.1 Water use efficiency 6.5.1 Integrated water management 6.6.1 Protect and restore water-related ecosystems 6.B.1 Local participation in sanitation management 12.2.2 Domestic Material Consumption	Reduce wastewater, flood risk, air pollution and material consumption for grey stormwater infrastructure. Provide habitats for urban wildlife and reducing	Shenzhen, China, has implemented nature-based solutions to infiltrate, retain, and store stormwater for future use [24], [25], [26].
Rainwater harvesting: Rain barrels, cistern, rainwater harvesting systems	Rainwater harvesting is one of the nature-based solutions to help mitigate water scarcity and improve drinking water quality with low cost and energy consumption.	6.3.2 Ambient water quality 6.4.1 Water use efficiency 6.5.1 Integrated water management 6.6.1 Protect and restore water-related ecosystems 6.B.1 Local participation in sanitation management 12.2.2 Domestic Material Consumption	Reducing water consumption; reducing stormwater runoff (flood protection); providing drinking water; in some parts reducing groundwater extraction.	Chennai's Metropolitan Water Supply and Sewerage Board requires rainwater harvesting structures as a compulsory prerequisite for accessing water and sewer connections for all new buildings[27].
Bioremediation: Constructed wetlands for wastewater treatments	Constructed wetlands can help purify wastewater from various sources. Suspended solids and trace metals are filtered and absorbed by plants. Through the decomposition process, microorganisms in the wetlands use organic materials and nutrients as food. Plants provide much of the oxygen needed by the organisms to live and grow.	6.3.2 Ambient water quality 6.4.1 Water use efficiency 6.5.1 Integrated water management 6.6.1 Protect and restore water-related ecosystems 6.B.1 Local participation in sanitation management 12.2.2 Domestic Material Consumption	Reducing wastewater; less material consumption for construction of conventional treatment system and less energy demand for operating these conventional systems as well as regulating stormwater runoff.	Ouagadougou Urban Park in Grenoble city, France. Constructed wetlands with reed bed filters collect and treat stormwater runoff from building roofs and roads. This supplies the park with irrigation water and reduces the discharge of stormwater into the municipal sewer system[28].

[24] https://www.epa.gov/nps/urban-runoff-low-impact-development#:~:text=The%20term%20low%20impact%20development,quality%20and%20associated%20aquatic%20habitat
[25] https://www.tandfonline.com/doi/pdf/10.1080/1573062X.2014.916314
[26] https://iwa-network.org/can-rainwater-harvesting-transform-cities-into-water-wise-cities/
[27] https://chennaimetrowater.tn.gov.in/initiatives.html
[28] https://www.globalwettech.com/references/ref-others/item/79-grenoble-urban-park-ouagadougou-france.html

2.5 Land Use

The configuration of urban areas is a critical determinant of resource consumption, environmental impacts, and human wellbeing well beyond city boundaries. Investments in urban built and living infrastructure have long-lasting implications for sustainability targets of multiple generations. Forward-looking urban design and management of city assets are central to building a sustainable future (Seto & Pandey, 2019). Urban policy to reduce intra-urban distances and reduce car dependency could reduce energy consumption, emissions, and pollution significantly[29]. Compact cities also reduce development pressures on land around the urban fringes. However, high urban density is associated with large embodied materials in buildings and urban infrastructure, high exposure to pollution, and congestion (Güneralp et al., 2017).

Policy	Description	SDG indicator	Environmental improvement	Examples
Compact urban form	In affluent and mature cities, higher transport costs and a compact urban form can decrease residential and transport energy use. In developing-country cities with emerging or nascent infrastructures, compact urban form and transport planning can encourage higher population densities and avoid lock-in of high carbon emission patterns for travel (Creutzig et al., 2015a).	8.4.1 Material footprint 9.4.1 CO_2 emissions per unit value-added 11.2.1 Public transport access 11.3.1 Sustainable urbanization rates 11.3.2 Urban planning management 11.7.1 Open spaces in cities 11.A.1 Urban and regional planning 12.2.1 Material footprint 13.2.2 Total greenhouse gas emissions per year	Reduce energy demand for travel, GHG emissions and pollution. Promote conservation of farmland and natural landscapes.	The OECD documented how current compact city practices in Melbourne (Australia), Vancouver (Canada), Paris (France), Toyama (Japan) and Portland (United States) can help achieve environmental and economic sustainability[30].
Enhancement of greenspace: Afforestation of Urban Brownfields	Converting abandoned land into green space.	6.3.2 Ambient water quality 6.6.1 Protect and restore water-related ecosystems 9.4.1 CO_2 emissions per unit value-added 11.3.1 Sustainable urbanization rates 11.3.2 Urban planning management 11.7.1 Open spaces in cities 11.A.1 Urban and regional planning 13.2.2 Total greenhouse gas emissions per year	Improving environmental quality and reducing GHG emissions and urban heat, expanding recreational spaces, increase urban biodiversity.	Leipzig, Germany, started urban redevelopment processes in 2001 to green the city through multiple mechanisms that include creating pocket forests and urban forests on large, inner-city brownfields. City residents were involved in tree planting and design from the beginning of the project (Rink & Schmidt, 2021).
Promoting urban agriculture: Community gardens/ Farm to table programs	Improving food security and creating revenue opportunities from selling surplus crops.	9.4.1 CO_2 emissions per unit value-added 12.2.2 Domestic material consumption 12.3.1 Global food loss 13.2.2 Total greenhouse gas emissions per year	Improving environmental quality and reducing GHG emission; improving food security	The City of Medellín, Colombia, has implemented urban gardens to promote the consumption of healthy products. In addition, this has allowed savings of around $18 per month per family participating in the program[31].
Promoting urban agriculture: Vertical farming	Vertical farming is growing crops in vertically stacked layers using soilless techniques, including hydroponics and aeroponics. It is suitable for high-density living areas and can help improve urban food security.	9.4.1 CO_2 emissions per unit value-added 12.2.2 Domestic material consumption 12.3.1 Global food loss 13.2.2 Total greenhouse gas emissions per year	Improving environmental quality and reducing GHG emission; improving food security	Due to its small land area for conventional agriculture, the Singapore government and private farming companies, launched the vertical farming initiative in 2010. This practice is contributing to achieve food self-sufficiency targets for the country. Parking rooftops have been made available to urban farmers and residents interested in gardening or looking for part-time work [32].

[29] https://www.oecd.org/cfe/regionaldevelopment/50524895.pdf

[30] https://www.oecd.org/greengrowth/greening-cities-regions/compact-city.htm#table

[31] https://www.acimedellin.org/urban-and-rural-kitchen-gardens-are-an-alternative-in-medellin-to-increase-food-security/?lang=en

[32] https://vertical-farming.net/blog/2021/03/11/a-little-history-on-the-most-recent-evolution-of-vertical-urban-farming-in-singapore/

Appendix A SDG indicators related to sustainable consumption and production in cities.

SDG 6 Ensure access to water and sanitation for all

Targets	SDG indicator	Indicator's definition	Goal
Target 6.3: Improve water quality, wastewater treatment and safe reuse By 2030, improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.	6.3.2 Ambient water quality	Proportion of bodies of water with good ambient water quality.	By 2030 improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials.
Target 6.4: Increase water use efficiency and ensure freshwater supplies By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.	6.4.1 Water use efficiency	Change in water-use efficiency over time. Water use efficiency is measured as total gross regional product divided by total freshwater withdrawals.	Substantially increase water-use efficiency across all sectors.
Target 6.5: Implement integrated water resources management By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.	6.5.1 Integrated water management	Degree of integrated water resources management implementation (0–100)	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.
Target 6.6: Protect and restore water-related ecosystems By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes.	6.6.1 Protect and restore water-related ecosystems	Change in the extent of water-related ecosystems over time	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes.
Target 6.B: Support local engagement in water and sanitation management Support and strengthen the participation of local communities in improving water and sanitation management.	6.B.1 Local participation in sanitation management	Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	Support and strengthen the participation of local communities in improving water and sanitation management

Source: *https://sdg-tracker.org/water-and-sanitation*

SDG 7 Ensure access to affordable, reliable, sustainable and modern energy for all

Targets	SDG indicator	Indicator's definition	Goal
Target 7.2: Increase global percentage of renewable energy By 2030, increase substantially the share of renewable energy in the global energy mix.	7.2.1 Renewable energy	Renewable energy share in the total final energy consumption. This is measured as renewable energy (inclusive of solar, wind, geothermal, hydropower, bioenergy and marine sources) as a share of final (not primary) energy consumption. Energy mix includes electricity, transportation and cooking/heating fuels.	By 2030, increase substantially the share of renewable energy in the global energy mix.
Target 7.3: Double the improvement in energy efficiency By 2030, double the global rate of improvement in energy efficiency.	7.3.1 Energy efficiency	Energy intensity measured in terms of primary energy and GDP. Energy intensity is measured as the quantity of kilowatt-hours produced per 2011 international-$ of gross domestic product (kWh per 2011 int-$).	By 2030, double the global rate of improvement in energy efficiency

Source: *https://sdg-tracker.org/energy*

SDG 8 Promote inclusive and sustainable economic growth, employment and decent work for all

Targets	SDG indicator	Indicator's definition	Goal
Target 8.4: Improve resource efficiency in consumption and production Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead.	8.4.1 Material footprint	Material footprint, material footprint per capita, and material footprint per GDP. Material Footprint is the attribution of global material extraction to domestic final demand of a country. The total material footprint is the sum of the material footprint for biomass, fossil fuels, metal ores and non-metal ores.	Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation.

Source: *https://sdg-tracker.org/economic-growth*

SDG 9 Build resilient infrastructure, promote sustainable industrialization and foster innovation

Targets	SDG indicator	Indicator's definition	Goal
Target 9.4: Upgrade all industries and infrastructures for sustainability By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.	9.4.1 CO_2 emissions per unit value added	CO_2 emissions per unit of value added (kilograms of CO_2 emitted per dollar of GDP).	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes

Source: *https://sdg-tracker.org/infrastructure-industrialization*

SDG 11 Make cities inclusive, safe, resilient and sustainable

Targets	SDG indicator	Indicator's definition	Goal
Target 11.2: Affordable and sustainable transport systems By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.	11.2.1 Public transport access	Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities.	Provide access to safe, affordable, accessible and sustainable transport systems for all by 2030.
Target 11.3: Inclusive and sustainable urbanization By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.	11.3.1 Sustainable urbanization rates	The ratio of land consumption rate to population growth rate	Enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement by 2030
	11.3.2 Urban planning management	The proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically.	Enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries by 2030.
Target 11.6: Reduce the environmental impacts of cities. By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.	11.6.1 Solid waste management	The proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities. This indicator measures the share of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated. Data is only available at the regional (not national) level.	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to municipal and other waste management
	11.6.2 Urban air pollution	Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air pollution
Target 11.7: Provide access to safe and inclusive green and public spaces. By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.	11.7.1 Open spaces in cities	Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities.	Provide universal access to safe, inclusive and accessible, green and public spaces by 2030.
Target 11.A: Strong national and regional development planning Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning.	11.A.1 Urban and regional planning	Proportion of population living in cities that implement urban and regional development plans integrating population projections and resource needs, by size of city	Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning by 2030.

Source: *https://sdg-tracker.org/cities*

SDG 12 Ensure sustainable consumption and production patterns

Targets	SDG indicator	Indicator's definition	Goal
Target 12.2: Sustainable management and use of natural resources By 2030, achieve the sustainable management and efficient use of natural resources.	12.2.1 Material footprint	Material footprint, material footprint per capita, and material footprint per GDP.	By 2030, achieve the sustainable management and efficient use of natural resources.
	12.2.2 Domestic material consumption	Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP.	By 2030, achieve the sustainable management and efficient use of natural resources.
Target 12.3: Halve global per capita food waste By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.	12.3.1 Global food loss	Global Food Loss Index, measuring the total losses of ag. commodities from the production to the retail level.	By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.
Target 12.4: Responsible management of chemicals and waste By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.	12.4.2 Hazardous waste generation	Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment.	Achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks by 2020
Target 12.5: Substantially reduce waste generation By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.	12.5.1 Recycling rates	National recycling rate, tons of material recycled.	By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

Source: *https://sdg-tracker.org/sustainable-consumption-production*

SDG 13 Take urgent action to combat climate change and its impacts

Targets	SDG indicator	Indicator's definition	Goal
Target 13.2: Integrate climate change measures into national policies, strategies and planning	13.2.2 Total greenhouse gas emissions per year	Annual tonnes of carbon dioxide equivalent (MtCO2e)	By 2030, reduce significantly GHG emissions.

Source: *https://unstats.un.org/sdgs/metadata?Text=&Goal=&Target=13.2*

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