THE CIRCULARITY GAP REPORT

Munich

Closing the Circularity Gap
in Munich

CIRCLE ECONOMY FOUNDATION

CIRCLE ECONOMY FOUNDATION

We are a global impact organisation with an international team of passionate experts based in Amsterdam.

We empower businesses, cities and nations with practical and scalable solutions to put the circular economy into action.

Our vision is an economic system that ensures the planet and all people can thrive.

To avoid climate breakdown, our goal is to double global circularity by 2032.

CIRCULAR REPUBLIC

Circular Economy is the basis for a prosperous, resilient and sustainable economy.

As part of UnternehmerTUM, Europe's largest centre for entrepreneurship and innovation, CIRCULAR REPUBLIC empowers companies and start-ups to realise circular economy innovations and develop new business models.

As a platform, the initiative connects relevant actors and aims to set system-changing impulses along the entire value chain.

BEHIND THE COVER

Munich, Bavaria's capital, is home to centuries-old buildings and numerous museums. The city is known for its annual Oktoberfest celebration and its beer halls, including the famed Hofbräuhaus, founded in 1589.

PARTNERS

Personio FOUNDATION

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IN SUPPORT OF THE *CIRCULARITY GAP REPORT MUNICH*

JANEZ POTOCNIK

Former European Commissioner for Environment, Oceans and Fisheries; Co-Chair of the International Resource Panel; Partner at SYSTEMIQ and advisor to thought-leading institutions such as the European Forest Institute.

'The world is beginning to wake up to the fact that it is not just recycling that is driving a circular economy. Munich already boasts advanced material collection and recycling schemes, but the core source of virgin raw material demand is consumption. Transforming towards a regenerative economy means shifting to a decoupled economy, where all goods run with maximised utility and are shared optimally with family, friends, neighbours and even the broader public. I am proud that Munich is making steps in this direction, backed by the strong message of the *Circularity Gap Report Munich*.'

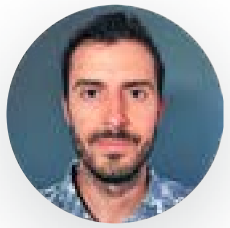
JONAS RIEKE

Chief Operations Officer at Personio; and Co-Founder at Personio Foundation.

'We are convinced of the transformative power of education and in channelling people's entrepreneurial spirit. The *Circularity Gap Report Munich*'s dedication to addressing circular economy challenges and opportunities with clear data is commendable. Achieving a more sustainable, circular future requires systemic change, collaboration and transparent metrics. We strongly believe in the power of education and entrepreneurship to drive a more sustainable, circular future.'

ARISTIDE ATHANASSIADIS

Co-founder of Metabolism of Cities and Senior Researcher at the Human-Environment Relations in Urban Systems laboratory of the Ecole Polytechnique Fédérale de Lausanne



'Cities are the most complex human artefact. They are the places where local and global challenges—whether environmental, political or societal—collide. They are also the places responsible for a major share of global resource use and polluting emissions. Therefore, there is an urgent need to better grasp this complexity and guide bold action. The *Circularity Gap Report Munich* manages to capture the environmental footprint of Munich as well as identify its main drivers. Going well beyond an unique socioeconomic cycling, this report helps underline the central importance of the building stock and its direct and indirect impact. In the future, this accounting framework should be generalised to test the effects of sufficiency (questioning societies' essential needs and their provision systems) and circularity in urban territories. This report provides a robust accounting framework which will lead to promising evidence-based policies.'

EXECUTIVE **SUMMARY**

Cities like Munich stand at the epicentre of the modern world, but are also hotspots of material consumption in our current linear global economy, exerting far-reaching impacts well beyond their borders. As densely-populated hubs that concentrate the majority of global economic activity,[1] infrastructure and technological development, urban centres are where people meet, create and innovate together. However, cities like Munich are also major centres of material consumption, emissions and waste generation. They exert immense pressure on the environment with environmental footprints that extend to other territories around the world, exceeding the boundaries of what our planet can safely replenish.[2] In an increasingly urbanised world, cities face the daunting challenge of accommodating population growth without exacerbating raw material extraction and pressures on the environment that could further threaten human well-being and economic resilience.[3,4]

The circular economy is a practical framework that puts forward an alternative way of producing and consuming within the limits of ecological systems. It does so by ensuring that material resources are used efficiently and effectively through strategies such as reducing material consumption, using materials for longer, using clean, regenerative materials and recovering secondary materials and using them again at their end-of-life. If managed appropriately and with a just transition in mind, the circular economy can deliver a range of benefits across environmental, social and economic indicators—from reducing resource, energy and water use, and waste and emissions, to shaping more resilient and thriving economies with a wealth of new jobs and activities for local populations.

With this report, we bring the *Circularity Gap Report* Methodology to a city for the first time. The *Circularity Gap Report Munich* provides data-driven insights into the city's metabolism and environmental footprint, which can help inform local decision-making. This means assessing how Munich consumes materials to meet its population's needs (sizing Munich's socioeconomic metabolism) and how different circular interventions could help the city reduce its material consumption while still allowing for the urban economy to thrive long-term. **Using 2019 as a baseline year**, this report uncovers how materials—metal ores, non-metallic minerals, biomass and fossil fuels—are extracted, used and disposed of to sustain Munich's demand, as well as the key drivers of these processes. It analyses how materials flow through the local economy as the starting point for measuring its circularity. As such, the report's main objectives are threefold: 1) Measure Munich's current socioeconomic metabolism to enable local stakeholders to better understand how the city consumes materials to satisfy its societal needs, 2) Identify key levers for accelerating the circular economy transition, and 3) Demonstrate the potential of circular economy interventions by measuring their effect on Munich's material and carbon footprints, to further place the circular economy on the agenda and inform local decision-makers and stakeholders.

Munich consumes enormous amounts of raw materials to satisfy its material demand. In 2019, Munich consumed 47 million tonnes of virgin materials, meaning that the average Munich resident consumed 32 tonnes of virgin materials and was responsible for 23 tonnes of CO_2 equivalent (CO_2e) that year. These figures are well above national, EU and global averages. Most importantly, Munich's material footprint is four times higher than what is estimated to be 'sustainable' level of consumption (8 tonnes per capita),[5] while the carbon footprint is ten times higher than the global target set for 2030 to limit global warming to 1.5-degrees.[6] A large portion of these material and carbon footprints are embedded in goods and products imported from Germany and the rest of the world, highlighting how Munich exerts environmental pressures well beyond its borders to meet its demand for materials.[7] Munich must thus address how materials are metabolised by the city's economy to mitigate climate change and environmental degradation—both at home and abroad.

Assessing Munich's circularity by looking at different material flows reveals that almost two-thirds of the virgin materials consumed are locked into stock, such as buildings, infrastructure, machinery and vehicles, while another third is represented by the consumption of fossil fuels for energy.

1. **Nearly 60%** of the materials consumed by the city in 2019 were **locked into stock**. These resources are not expected to be available for reuse or recycling for many years to come. Therefore, it is imperative to consider other circular interventions focusing on extending their lifetime as much as possible, such as designing for durability, adaptive reuse, repair and renovation, which also minimises construction and demolition waste.
2. **Another 30%** of material consumption consists of **fossil fuels** used as energy carriers. Optimising energy consumption and prioritising renewable energy sources are, therefore, clear opportunities for Munich to substantially reduce its environmental impact.
3. **Non-renewable inputs**—such as certain metals, chemicals, glass and plastics—make up **6% of total material use**. Although these materials have the potential for cycling, Munich has not yet fully tapped into this opportunity. This is another avenue for the city to enhance its circular economy efforts.
4. Munich's **ecological cycling potential**, which includes renewable, carbon-neutral biomass resources like food crop residues, timber and wood products with the potential for cycling, accounts for just 2.3% of the total materials consumed. This could be increased by prioritising the consumption of renewable materials, in particular as substitutes for finite virgin materials.
5. Munich's share of **secondary material consumption** (Socioeconomic cycling metric) is **2.4%**. This means that the consumption of secondary materials as a share of total material consumption is relatively low. Prioritising recycled materials as inputs for new production of goods and in construction can help increase this number and, most importantly, reduce the need for virgin materials.

Clearly, a high-impact area is stock build-up: Munich must focus on optimising the use and expansion of the building and infrastructure stock of the city. Reducing the relatively high share of fossil fuel consumption (non-circular inputs) is also a priority, especially considering efforts to decarbonise its economy.

The Built environment—including Construction and the use of (commercial, residential and public) buildings—and Manufacturing concentrate over three-quarters of Munich's material footprint and two-thirds of its carbon footprint. Manufacturing is the single largest contributor to the material and carbon footprints, much of which can be attributed to Munich's flagship activities such as motor vehicle manufacturing, and the manufacturing of machinery and equipment, electronics, furniture and clothing. As a result of the city's expansive urban development, **Construction** also claims an important part of the material footprint. This activity is set to remain significant as the city continues expanding in the coming years and deep retrofit renovation projects become increasingly frequent with continuous public infrastructure maintenance. The **Built environment** is a key feature of the urban space and a crucial determinant of Munich's socioeconomic metabolism. The Built environment encompasses many activities that arguably make it the most important area in which to apply circular interventions to reduce Munich's material and carbon footprints, from the materials used to build and maintain public infrastructure to the consumption of fossil fuels for heating in different commercial and public buildings. It is no surprise that these resource-intensive sectors contribute to the majority of Munich's environmental impact. However, they are also vital contributors to the city's economy, both in terms of value-added and employment. These sectors will remain pivotal, serving as key components in the city's efforts to reduce carbon and material footprints, both locally and globally.

The circular economy is a 'means to an end': circular strategies targeting five of Munich's key societal needs could alleviate the environmental pressures associated with its current material use. This report explores **five 'what-if' scenarios** to quantify the potential of circular economy strategies to transform Munich into a more resource-light and low-carbon city. Each scenario models a combination of strategies to enhance circularity across the 'four flows': using less (narrowing flows), using longer (slowing flows), making clean (regenerating flows) and using again (cycling flows). These scenarios are: 1) Build a circular built environment, 2) Shift to a circular food system, 3) Advance circular manufacturing, 4) Promote a circular lifestyle and 5) Rethink mobility.

Interventions related to the Built environment, Manufacturing, and the adoption of a Circular lifestyle emerged as the most impactful in reducing both material and carbon footprints—marking the leverage points for Munich to act upon. Combined, the scenarios have the potential to reshape Munich's development trajectory, bringing the material footprint down from 32 to 19 tonnes per capita, below the German average (21 tonnes per capita) and almost equal to the EU average (18 tonnes per capita). They have the potential to reduce the carbon footprint from 23 to 18 tonnes of CO_2e per capita—a 23% reduction. For Munich, this would mark a crucial milestone towards reaching global sustainable material and carbon footprint levels. What's more, the impacts of the circular economy strategies go well beyond reducing material use, waste generation and greenhouse gas emissions, providing a wealth of other co-benefits. These strategies can help Munich increase value retention and strengthen its local economy. This benefits Munich's small- and medium-sized enterprises (SMEs) and residents, for example, by engaging local organisations, which also help offer unemployed people professional training and stable job prospects.[8] Bolstering resource efficiency and making more from less can deliver cost savings and help diversify and shift the productive industries towards more technology-intensive sectors, but also towards adopting circular business models. For Munich, this could mean leveraging the expertise and infrastructure of major automotive companies to implement large-scale Mobility-as-a-Service and other urban mobility solutions, for example.[9] Most importantly, in a high-consuming economy like Munich, adopting circular practices can be a key lever to foster a more efficient and sufficient economy while achieving a significant reduction in overall (consumption-based) material and carbon footprint. Fostering a systemic transition to a circular economy has the potential to make Munich a more resilient, sustainable and prosperous city, which are fundamental building blocks for increasing well-being among Munich's residents, as well as for sustaining economic prosperity in the long term.

With the circular economy at the core of the city's economic, social and environmental agendas, Munich is ready to pursue its journey towards becoming a resource-light and low-carbon city and a hotspot for circular innovation. Although Munich has a way to go in reducing its material and carbon footprints and its global impact, the city is well poised to take on the challenge. As a European and global hotspot for innovation and R&D, the city has the means and motivation to pull the key levers to advance circularity across the five focus areas analysed in this report. Munich can lead by example and become a front-running city by placing the circular economy at the forefront of its economic, social and environmental agendas. Everyone in the city will have a role to play in changing their consumption patterns and prolonging the lifetime of products and materials through new circular business models. Fortunately, the circular economy is no longer an abstract concept in Munich, and stakeholders are already taking action to make the city more circular. Our deep dive into different scenarios reveals several examples of how private stakeholders, community-led initiatives and local authorities are stepping up to mobilise the local population and business ecosystem to engage in various circular practices. Munich has the opportunity to build on these existing circular initiatives, businesses and projects to make them mainstream and disrupt the linear status quo.

Achieving a more circular economy requires more than technical solutions. A joint vision is needed; and the cooperation of all relevant stakeholders—from city administration to businesses, academia, and local communities—will be crucial for the successful implementation of a circular economy in Munich. This report lays the path forward for a more circular Munich and suggests governmental action on the following recommendations:

1. **Use the results of this report to shape a holistic understanding of the circular economy.** As the scenarios and proposed interventions point out, there is more to circularity than material cycling. Therefore, taking action will require finding solutions that use less materials, use them for longer, and ultimately do so in a way that regenerates natural systems.
2. **Inform a fit-for-purpose, evidence-based circular economy strategy for Munich.** Based on this report's findings, begin to develop the vision, goals, milestones and actions that will guide long-term circular implementation, led and governed by the City through a participatory approach.
3. **Establish an innovative and comprehensive governance framework to guide the transition and take action.** The City will be integral in guiding Munich's upcoming circular strategy. It can do so by mobilising stakeholders, educating the public community, managing the urban environment to enable and facilitate circular practices, supporting local businesses and enforcing regulations.
4. **Align action across all relevant stakeholders to ensure a successful systemic transition.** Leverage the knowledge of local experts, the power of Munich's main business sectors, and the momentum that local early adopters are already building on the ground to deploy the circular economy on all fronts. It will also be necessary to align policies and regulations made locally with higher levels of governance, at state, national and supra-national levels.
5. **Support the business community in engaging in the transition.** The City can leverage Munich's strong business ecosystem to lead essential activities of this circular transition. For key sectors of the economy, large companies can play an important role in reducing their use of materials throughout their operations while the city can support SMEs and entrepreneurs in creating new circular business models.
6. **Measure, monitor and evaluate progress across all aspects of the circular economy.** Ensure a fit-for-purpose monitoring framework is developed that captures all aspects of the circular economy—not just cycling. Align this with existing environmental goals and use it to set local targets and milestones.

CONTENTS

1. INTRODUCTION

The current linear economic model has caused the transgression of six of nine planetary boundaries, largely due to exponentially increasing raw material extraction and consumption. Cities lie at the core of this system: they are home to more than half the global population and driving the majority of economic output. They are also the final destination of the linear 'take-make-waste' model, exerting far-reaching environmental impacts at local, regional and global scales. The circular economy is an alternative system that can be employed to address these challenges, with the goal of re-organising the economy into one that allows societies to operate within safe ecological limits. Given cities' key role in the global economy, the potential for a circular transition is particularly relevant in the urban context. In this sense, Munich serves as a perfect example of a city that is striving to transform from a linear model to a more circular, sustainable and resilient economy. By engaging both public and private actors and leveraging its strong industrial ecosystem in a number of circular initiatives, Munich is already showing the political will to engage in this transition towards a decarbonised, resource-efficient and thriving city, but also a global hub for circular innovation.

THE CURRENT STATUS OF THE GLOBAL ECONOMY

Strong scientific evidence suggests that we have entered a new geological era called the Anthropocene, in which human activity has emerged as the dominant driver of Earth systems change, inflicting multiple and measurable changes to planetary stability.[10] As of 2023, six of the nine planetary boundaries supporting life on Earth have been crossed, meaning that humanity is pressuring Earth's resources and systems in a way that goes beyond what the planet can sustain and safely regenerate.[11] This is evidenced by the fact that the planet has entered its sixth mass extinction,[12] while global atmospheric CO_2 concentration is at its highest level in millions of years.[13] Ecological overshoot can be primarily attributed to exponential growth in raw material extraction,[14] which has more than tripled globally since 1970, reaching a staggering 92 billion tonnes a year in 2019. This is expected to double again by 2050 if business as usual continues.[15] Rising material extraction has shrunk global circularity from 9.1% in 2018 to 7.2% in 2023, indicating that over 90% of materials used are from virgin sources.[16] Meanwhile, the responsibility of surpassing planetary boundaries is not equally distributed: the material and carbon footprints of high-income nations account for the bulk of the overshoot.[17, 18] It is clear that our current socioeconomic model is due for a major upgrade. Revamping resource management to satisfy societal needs lies at the heart of building a new model that prioritises human well-being within ecological limits.

CITIES IN THE GLOBAL ECONOMY

Against this backdrop, cities emerge as the epicentre of the modern world. With urban areas now hosting the majority (55%) of the world's population, a share projected to rise to almost 70% by 2050, their significance cannot be overstated.[19] Cities also concentrate the majority of economic activity, contributing almost 80% of global economic output.[20] Additionally, they function as vital transportation hubs and concentrate most of the human-made infrastructure and spaces that make up the built environment. They are also dynamic cultural, creative and educational hotspots—where people live, work and gather—and are often at the forefront of innovation and technology development. But cities also concentrate the bulk of material flows and consumption in the current linear economy model (before becoming waste), driving ecological breakdown along the way. Despite covering a mere 3% of the global land area, cities' environmental footprints are far-reaching, responsible for around two-thirds of global greenhouse gas (GHG) emissions, material consumption, energy demand and waste generation.[21] With growing urbanisation and the global population expected to swell by 2.5 billion people by 2050, new and existing cities face the daunting task of accommodating this growth. Failing to address linear dynamics will mean that the expansion of urban areas will further intensify raw material extraction and consumption, projected to almost double from 2011 levels and reach 167 billion tonnes by 2060.[22] This will accelerate mounting environmental pressures, further threatening human wellbeing and economic resilience.[23] Cities are at the forefront of this complex set of challenges.[24] Actions taken by cities will largely influence humanity's ability to stabilise Earth's life support system within safe and just boundaries.[25, 26]

THE CIRCULAR ECONOMY

The circular economy is being increasingly recognised as a new sustainability paradigm, an alternative system that offers a way of producing and consuming within biophysical limits. In a circular economy, the transformation of raw materials into social benefits is optimised by designing out waste, using everything at its highest value for as long as possible and regenerating natural systems. If managed well and with a just transition in mind, the circular economy can deliver a range of benefits across environmental, social and economic domains. By narrowing, slowing, regenerating and cycling material flows (see page 32), maximising resource efficiency, advancing consistency in technology use and promoting sufficiency, it minimises waste generation and environmental pollution. As about 70% of global emissions are tied to material use and handling, the circular economy can also be the missing link in the race to net zero.[27] The circular economy, climate and biodiversity agendas are inherently intertwined, and cities are at the heart of the solutions.

CIRCULAR CITIES

Circular cities are characterised by careful resource management throughout products' and materials' lifecycles, with a strong emphasis on regeneration, reduction, reuse and (re)cycling.[28, 29] Buildings, for example, are modular, flexible and designed for repurposing instead of demolition. Renewable energy sources, such as solar and wind power, are utilised locally and regionally. Citizens benefit from efficient and non-polluting mobility systems powered by renewable energy, automated with sharing, pooling and on-demand services. Finally, circular cities promote a local urban bioeconomy, in which all organic waste and by-products are recovered and used as feedstock for nutrient or chemical recovery, and urban and peri-urban farms are the norm—promoting the consumption of local foods and use of resource-efficient technologies.[30] This approach benefits people, the environment and the economy. People in circular cities experience an enhanced quality of life, benefiting from cleaner air, reduced waste and greater access to green spaces. The environment benefits from reduced pressures due to decreased resource consumption, lower GHG emissions and improved biodiversity.[31] Economically, circular cities foster innovation, job creation and economic resilience by promoting local circular supply chains and supporting circular business models. By integrating sustainable practices into urban planning, circular cities provide a blueprint for a sustainable future where the wellbeing of people and the planet is prioritised.

MUNICH: THE IMPACTS OF A LINEAR CITY

Munich, the vibrant capital of Bavaria and the third largest city in Germany, holds the potential to become a European circular capital. Germany's economy is largely driven by high consumption, which exerts excessive environmental pressures both locally and abroad.[32] In 2023, the country reached its national overshoot on the 4th of May, meaning its resource demand surpassed what the Earth can regenerate in a year in less than five months. In other words, if everyone were to live like the average German, we would need approximately three Earths to sustain and fulfil the need for natural resources.[33] Germany's impact extends beyond its borders due to its role as a global player in international markets, with significant trade and export activities contributing to material extraction, GHG emissions, and other environmental pressures worldwide. High-income nations like Germany need to fundamentally reduce their ecological footprint by shifting from a linear way of producing and consuming to a circular one. Like other major urban centres, Munich significantly contributes to Germany's overall footprint due to its affluent status. Despite its population representing just over 11% of Bavaria, Munich contributes over 19% to the state's economic output, with a per capita purchasing power 35% higher than the national average.[34]
The city's high average income levels result in high consumption rates and subsequent environmental impacts. However, this also means that Munich can leverage its position as an economic, social and cultural hub to spearhead the transformation towards a thriving society within planetary boundaries.

A CIRCULAR MUNICH

Transforming Munich from linear to circular will require deep changes in politics, public services, business and society overall, which will impact how the city functions: how the built environment is managed, the food system operates and mobility patterns are shaped, for example. To ensure a systemic change that builds upon Munich's strengths and serves all of society, this transformation needs to be led by the public-private sectors and involve Munich's citizens. The Municipality is already playing a key role in the transformation by, for instance, being part of the EU's Circular Cities and Regions Initiative (CCRI)[35] as a pilot city.[36] The city also has plenty of opportunities and potential. Munich's economic position, renowned for its tradition of innovation and technological advancements,[37, 38] serves as a fertile ground for driving circularity. The city also boasts a wide range of bottom-up initiatives that serve as a basis for the scaling up of circular, regenerative and sustainable initiatives.

Policy landscape

Aware of the potential benefits of the circular economy, the City of Munich's local government is leading by example, setting strategies and targets for a local circular economy. As a policy-maker within a multi-level governance system, the City of Munich has the agency to enact local ordinances that foster environmental sustainability and circular economy practices. As a policy-taker, the City must also adhere to the climate and environmental laws set by the Bavarian state government, the Federal Government of Germany and the EU. These entities provide the broader legislative framework and targets at the national and EU levels, within which Munich must formulate its localised policies.

While setting the right policy and regulatory frameworks to accelerate the circular transition typically falls under the responsibility of national-level policymaking, local governments like Munich are essential in building a sustainable future by taking proactive steps and establishing their own strategies and targets, if possible in alignment with broader legislative frameworks. Via ambitious targets and commitments, Munich is ready to take its next steps to lead the circular transition in the country. In December 2019, the city set the goal of achieving climate neutrality by 2035.[39] To this end, the Munich City Council adopted *Circular Munich—Circular Economy for a Sustainable Munich* in July 2020, emphasising the city's vision for a circular economy and zero waste future.[40] This resolution highlighted the importance of collaboration across urban society, the economy and institutions in evolving into a Circular City. Munich is also part of the EU's Circular Cities and Regions Initiative as a pilot city and, since April 2022, has actively participated in the European Commission's 100 EU climate-neutral and smart cities initiative.[41]

These policies operate within a growing enabling policy environment. At the EU level, the EU *Green Deal*[42] and the *Fit for 55* package[43] are the cornerstones of climate commitments, while the *Circular Economy Action Plan*[44] is one of the main building blocks for circular economy policymaking. Nationally, the *Climate Change Action Plan*[45] guides Germany's long-term strategy for climate action, while the Climate Change Act[46] legally reinforces the goal of achieving climate neutrality by 2045. In 2021, Germany's Circular Economy Initiative developed a *National Circular Economy Roadmap* on behalf of the Federal Ministry of Education and Research,[47] while the Federal Government is currently leading the development of the *National Circular Economy Strategy*.[48] Following the Climate Change Act, many federal states and municipalities across Germany have created their own binding policy frameworks for climate-friendly actions to attain federal climate goals. At the state level, for example, Bavaria has put forward a set of strategies which feature circular economy principles and strategies for transforming its economy, tackling different domains, such as the energy system[49] and the bioeconomy[50] to achieve climate neutrality by 2045.[51]

Innovation and business landscape

In addition to solid policy development, the city boasts a thriving business and start-up ecosystem. Bavaria is a hotspot for manufacturing industries, and Munich is a highly industrialised metropolitan area, hosting a number of multinational companies—in particular in automotive and mechanical engineering industries, but also in electronics and technology. The city's strong industrial and entrepreneurial ecosystem provides a platform for entrepreneurial ventures focused on renewable energy, sustainable transportation, waste management and other circular business models. Munich is also a hotspot of business innovation: it was ranked as the fourth most innovative city in Europe, based on a range of indicators, including (among others) economic development, culture, business and financial services, education, science and technology, sustainability and spatial planning.[52] Munich is already a haven for circular economy businesses in Germany—harbouring one-fourth of the country's circular start-ups and attracting one-fourth of all funding.[53] Circular Republic, an initiative of UnternehmerTUM, Europe's largest centre for entrepreneurship and innovation, supports companies in developing circular economy innovations at the core of their business models and sets up large cross-company collaborations to close the loop for specific sectors and products.[54]

Local action landscape

Munich's circular ecosystem expands beyond municipality- and business-led initiatives. Munich is also at the forefront of championing circular economy principles through a combination of actions and contributions from local and civil society initiatives and third-sector organisations. Plenty of examples showcase this: Munich's network of repair cafés and upcycling workshops, urban gardening and community kitchen projects, and community initiatives such as Nachbarschaft, to name a few. Circular Munich, an open community of citizens co-creating a more circular city, is another organisation working at the intersection of cities, nature and placemaking, with its activities spanning across areas such as education, fashion, food, products and transportation.[55] These examples provide important insights into the degree to which local, bottom-up initiatives are already underway.[56]

Leveraging these strengths, including its cultural heritage and commitment to a high quality of life, Munich's conducive environment for sustainable practices can initiate innovative circular solutions that reduce resource use and foster environmental sustainability while upholding (and even improving) the well-being of its residents. This transformation is crucial to tackling the burdens of overconsumption from high-income cities on local, national and global environmental pressures.

TOWARDS A CIRCULAR MUNICH

Monitoring and evaluating progress in advancing circularity requires metrics and indicators. For Munich to truly lead in this transformation, measuring a baseline—the current state of circularity—and progress over time is crucial. The baseline assessment of the city enables stakeholders to better identify and prioritise key areas or sectors with the highest potential for circular action and set realistic and informed targets for the transition.

So, how circular is Munich? And what benefits can circularity bring to the city? As of 2023, we can finally answer this question by applying the *Circularity Gap Report* methodology at the city level. Building upon the expertise of its Cities Programme, which has supported and guided over 50 cities and regions globally over the past 12 years in putting the circular economy into practice, Circle Economy Foundation is turning a new page in urban circular research: **CGR for Cities**. This report is the very first *Circularity Gap Report* produced for a city. It aims to provide a data-driven, factual approach for Munich to identify how materials flow throughout the economy—mapping Munich's 'urban metabolism'—pinpoint hotspots of consumption and production, and investigate how possible interventions could help the city reduce its material and carbon footprint to inform future goal-setting and agendas. To ensure our data is in line with the reality of the city, Circle Economy Foundation coordinated with Circular Republic and other stakeholders, such as the City of Munich.[57]

2

SIZING MUNICH'S MATERIAL FLOWS

The material reality of meeting societal needs

This chapter dives into Munich's socioeconomic metabolism, exploring how—and in what proportions—materials flow through the economy to meet various societal needs and wants. The results provide key insights that illustrate the relationship between Munich's economy and material consumption: the city exhibits high per-capita material and carbon footprints, well above the German and EU averages. A few sectors, namely the Built environment and Manufacturing, concentrate the bulk of the material and carbon footprints. Munich's material consumption is also a key driver of environmental impacts that extend well beyond the city's and Germany's borders—the city outsources the impacts of its consumption to the rest of Germany and around the world.

MUNICH'S SOCIOECONOMIC METABOLISM: MEASURING MATERIAL FLOWS AND ENVIRONMENTAL FOOTPRINTS

Cities consume material resources, water and energy to operate, a set of processes often referred to as their 'metabolism'. This analysis takes the socioeconomic metabolism of Munich—that is, the way in which raw materials flow through the city's economy and are kept in long-term use to meet the needs of the urban population—as the starting point for measuring its level of circularity. Knowing how materials are extracted, transformed, delivered, consumed and wasted in an urban economy is essential for identifying and addressing opportunities for a more circular city. While the analysis focuses on materials, their use is largely interwoven with other natural resources such as land and water. Figure one provides a depiction of Munich's socioeconomic metabolism using 2019 as the baseline year. It shows the amounts of materials (clustered into four key material groups) embodied in what the city consumes and produces (read more in Appendix B, on page 103).

Munich's socioeconomic metabolism reveals a highly material-intensive economy, with a few sectors concentrating the bulk of material- and carbon-intensive activities. This is largely due to 1) high consumption rates from Munich's citizens and economic activities and 2) systemic inefficiencies in how materials are used throughout different value chains to satisfy various societal needs, particularly those for housing, mobility and manufactured goods. As with any major city, Munich's large raw material consumption is highly dependent on activities happening beyond the city's borders, across global value chains. This means that beyond generating significant volumes of waste and emissions in the city, Munich also drives material extraction in the rest of Germany and abroad.

THE MATERIAL FOOTPRINT SATISFYING SOCIETAL NEEDS IN MUNICH

Satisfying societal needs requires energy and materials. In fulfilling citizens' needs, it is important to consider how materials and energy are put to work to deliver social outcomes via provisioning systems. Provisioning systems comprise physical assets, such as urban infrastructure, technologies and their efficiencies,[58] and social elements, which include government institutions, businesses, communities and markets.[59] Provisioning systems are the essential link between how materials and energy are used, and their social outcomes. For example, different types of buildings (private housing versus shared apartments, private office spaces versus multi-purpose building spaces) can provide similar functions but require very different quantities of materials.

The linear economy is characterised by a wide range of goods and services with large ecological footprints, which, in many cases, do not contribute to the improved well-being of people. The circular economy can satisfy social needs but with a much lower environmental impact. On the next page, we describe the seven key societal needs and wants—and the products and services they include—as well as the volume of materials it takes to fulfil them from Munich's total material consumption of 48 million tonnes.[60]

SEVEN SOCIETAL NEEDS & WANTS

HOUSING

14.6 million tonnes (30% of total material consumption)

Housing is the largest driver of Munich's total material consumption. This includes the construction, maintenance and renovation of housing with materials such as concrete, steel and timber.

MANUFACTURED GOODS

11.6 million tonnes (24% of total material consumption)

Manufactured goods account for an important share of material consumption and consist of a diverse group of products—such as appliances, furniture, clothing, cleaning agents, personal-care products and paints—that generally have short to medium lifetimes in society. Textiles also consume many different resources, such as cotton, synthetic materials like polyester, dye pigments and chemicals. Manufactured goods belonging to other societal needs—such as vehicles and capital equipment for healthcare—are not included in this category.

MOBILITY

7.4 million tonnes (15% of total material consumption)

A share of total material consumption is taken up by the need for mobility. Specifically, two material types are used: the materials (especially metals) used to build transport technologies and vehicles like cars, trains and aeroplanes and, most importantly, the fossil fuels used to power them.

PUBLIC AND COMMERCIAL SERVICES

5.2 million tonnes (11% of total material consumption)

The delivery of services to society ranges from all public services, except healthcare and education, to commercial services like banking and insurance. This typically involves the use of buildings, professional equipment, office furniture, computers and other infrastructure.

NUTRITION

4.6 million tonnes (10% of total material consumption)

Agricultural products such as crops and livestock are used to create food and drink products. These tend to have short life cycles in our economy, being consumed quickly after production.

HEALTHCARE AND EDUCATION

3.3 million tonnes (7% of total material consumption)

Providing healthcare and education is crucial to improving quality of life. This requires materials for buildings and their operations—maintenance, heating, cooling and food services—as well as a wide range of medical and educational equipment, for example.

COMMUNICATION

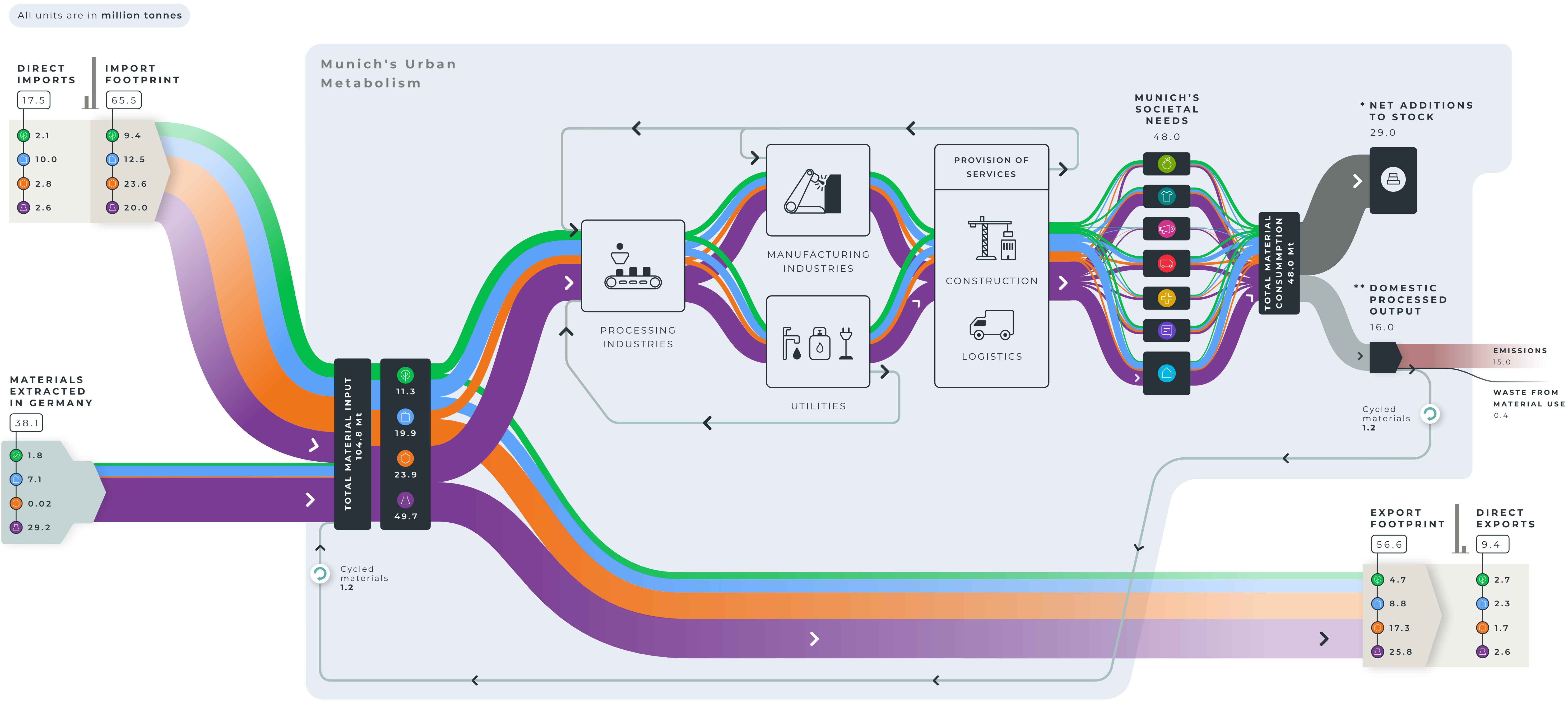
1.3 million tonnes (3% of total material consumption)

Communication is an increasingly important aspect of today's society, provided by a mix of equipment and technology ranging from personal devices to data centres.

** Figures may not sum to total due to rounding.*

X-RAY OF MUNICH'S ECONOMY

Figure one shows an X-Ray of Munich's economy: the materials that feed into meeting key societal needs.



MATERIALS EXTRACTED IN GERMANY - **38.1**

BIOMASS	FOSSIL FUELS	ORES	MINERALS
1.8	7.1	0.02	29.2

SOCIETAL NEEDS - **48.0**

NUTRITION	MANUFACTURED GOODS	COMMUNICATION	MOBILITY	HEALTHCARE & EDUCATION	SERVICES	HOUSING
4.6	11.6	1.3	7.4	3.3	5.2	14.6

* Net additions to stock
Includes buildings, machinery, inventories

** Domestic processed output
Includes emissions to air, water and soil, and solid and liquid waste

	MUNICH TOTAL	MUNICH PER CAPITA	GERMANY PER CAPITA	EU PER CAPITA	GLOBAL PER CAPITA
Domestic extraction	38 million tonnes[61]	26 tonnes	11 tonnes	10 tonnes	12 tonnes
Material footprint	47 million tonnes	32 tonnes	21 tonnes	18 tonnes	12 tonnes
Carbon footprint	34 million tonnes of CO_2e	23 tonnes of CO_2e	14 tonnes of CO_2e	10 tonnes of CO_2e	6 tonnes of CO_2e-

Table one compares regional and global figures for material extraction and consumption, as well as consumption-based emissions.

DOMESTIC MATERIAL EXTRACTION

In this report, 'domestic extraction' reflects the materials extracted within Germany to satisfy Munich's material consumption, as only a minimal share of the total materials consumed by the city are extracted within the city and the broader Metropolitan Region. Domestic extraction measures, in tonnes, the amount of raw materials extracted from the natural environment in a given system for use in the economy, and as such, is one of the indicators contributing to the overall material footprint.[62, 63] Domestic extraction is, therefore, a robust proxy to indicate the magnitude of domestic environmental impacts of activities such as mining and agriculture (GHG emissions, soil erosion and degradation, biodiversity loss and the pollution of ecosystems, for example). In 2019, around 38 million tonnes of materials were extracted in Germany and channelled towards Munich's economy: equivalent to nearly 26 tonnes per capita. Domestic extraction can be further broken down into materials that are directly consumed in the city and the share that is exported from Munich's economy. In the case of Munich, 59% of domestically extracted materials are consumed in the city, and the rest (41%) are exported elsewhere, either directly as raw materials or in the form of goods and products.

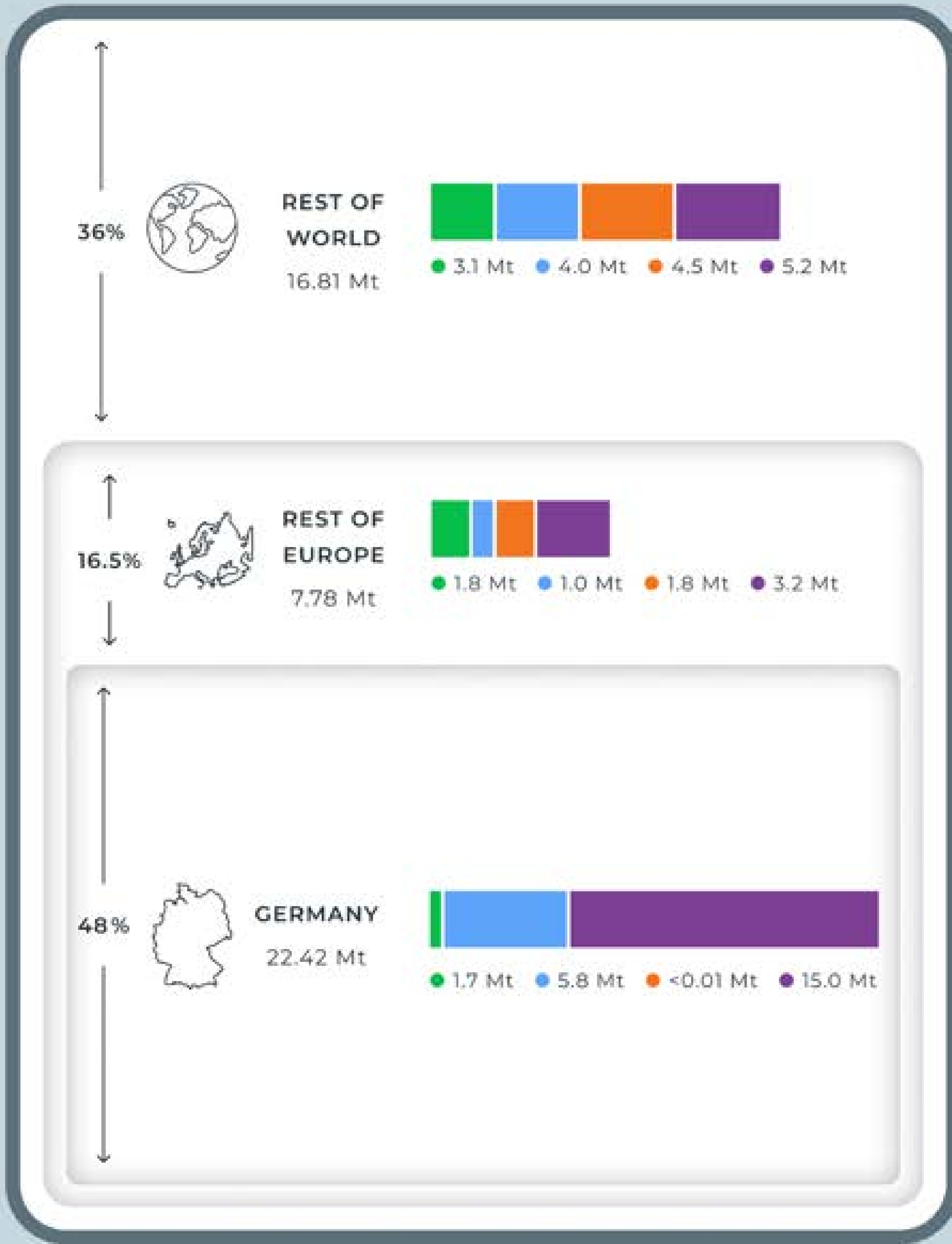
Further breaking down domestic extraction by material group provides insight into the type of materials that are sourced from relatively near locations (within the national boundaries) and that serve to satisfy the demand for primary raw materials from households, businesses and public institutions in Munich. **Non-metallic minerals**, particularly rocks, gravel and sand, contribute the largest fraction of material extraction within Germany (around 76% of the total by mass). In fact, Bavaria has a long history of mining various minerals and currently, aggregates and building materials (such as sand, gravel, loam and limestone) remain the primary source of material extraction taking place in the state and currently contribute to making Bavaria the **second most extractive state** in Germany.[64, 65] **Fossil fuels**, in the form of coal, are the second-most domestically extracted material (around 19%),[66] consisting primarily of coal extraction from North Rhine-Westphalia, Saxony and Brandenburg.[67] Lastly, **biomass** extraction only accounts for around 5% of total domestic extraction. This is attributed to the farming of crops (such as potatoes, wheat, barley, rapeseed and maise) but also forestry activities related to timber. Bavaria is known for its agriculture and forestry industries, which have particular importance in the state's economy.[68] Its extensive forests cover almost one-third (31%) of the state's territory and provide timber and other renewable raw materials such as biological feedstock for energy production, increasingly for bio-chemical production.[69] Although Bavaria is the largest extractive state for biomass in Germany, with 59 million tonnes of biomass extracted in 2019,[70] much of this is slated for export: Bavaria is a net exporter of agricultural products.[71] This means that much of this extraction cannot be attributed to extraction for the city of Munich. While **metal ores** constitute around 13% of Munich's total material footprint (around 6 million tonnes), statistics show that none of this ore is actually extracted within Germany, and only a limited amount comes from other European countries (almost 2 million tonnes). Overall, domestic extraction plays a key role in satisfying Munich's material demand. However, it is only one of the indicators contributing to the city's overall material footprint.

MATERIAL FOOTPRINT

To satisfy its total material demand, Munich imports many materials and products from abroad. Taking a consumption-based material flow account allows us to measure the amount of materials used to meet the consumption needs of a city like Munich, regardless of where the materials were extracted or where the products were produced. This approach accounts for the physical flows of materials embodied in imported products and the flows of materials exported in the form of products and services. Thus, the material footprint, also referred to as Raw Material Consumption (RMC), is the total amount of raw materials extracted to meet the final demand of an economy. This is especially relevant when analysing systems like Munich, a highly developed, densely populated city with complex infrastructure networks and a large built environment. Taking such an approach to estimate the material flows that feed into Munich's economy provides a more holistic perspective of the environmental consequences of the city's metabolism well beyond the city boundaries.

Munich needs large quantities of raw materials to supply the goods and services it consumes. These are extracted at different points along national and international supply chains. Munich's total material footprint in 2019 stood at 47 million tonnes, or almost 32 tonnes per capita, compared to the German average of 21 tonnes per capita in the same year.[72] Both Germany and Munich's per capita material footprints are well above the global average (12 tonnes per capita per year) and also largely exceed the estimated sustainable level of 8 tonnes per capita.[73] There is a clear global correlation between a society's material footprint and the way its economy is organised, especially in terms of its efficiency, affluence (average income levels) and population density.[74, 75] This analysis thus reflects the economic reality of a city like Munich: a major European metropolis and a highly industrialised economy with important activities, such as the manufacturing and construction industries, which, apart from contributing to the local economy, also have a high environmental cost both at home and abroad.

Figure two depicts the breakdown of Munich's material footprint by material group and region of origin.



TOTAL MATERIAL FOOTPRINT: 47 Mt

Munich's material footprint originates well beyond the city's boundaries. Overall, it can be broken down between the shares of the footprint embedded in imports from Germany, the rest of Europe, and the rest of the world (Asia & Pacific, Africa, North and South America).

By taking a consumption-based approach, the environmental burden of raw material extraction can be attributed to the place of final consumption—in this case, Munich.

Legend

Biomass · Fossil fuels · Metal ores · Non-metallic minerals

Munich's footprint can be tracked well beyond the city's borders. From a raw materials perspective, more than half of the city's material footprint is embedded in imports from outside the German territory. A substantial portion of the total material footprint (17%) is embedded in imports from the rest of Europe, while the largest share of the footprint in imports comes from the Asian and Pacific countries (24%). In comparison, the footprint embedded in imports from the rest of the world regions (Latin America, Africa and North America) contribute minimally to the total (6%, 3.5% and 2.3%, respectively). However, these imports are particularly relevant in satisfying a significant portion of Munich's demand for metal ores. The rest of the footprint originates within Germany and is reflected in what is considered domestic extraction (largely driven by the extraction of non-metallic minerals and fossil fuels). Overall, the city relies greatly on mineral and fossil materials extraction within Germany, while much of the material footprint also comes from material extraction abroad, particularly in other European countries and the Asia and Pacific region.

The consumption of non-metallic minerals dominates Munich's material footprint. Materials such as construction aggregates, gravels, clay, sand and others contribute to almost half of the total material footprint (50%), or around 23 million tonnes. Non-metallic minerals are expected to significantly contribute to the total footprint, as cities typically concentrate on construction activities and overall built environment development, such as urban landscape infrastructure (buildings and infrastructure such as roads, underground systems, and bridges, for example) and industrial sites. The second largest contribution to the material footprint is the consumption of **fossil fuels** (23% or 11 million tonnes), primarily coal extracted within Germany and gas and petrol products imported from the rest of the world. This is followed by **biomass**, which makes up around 14% of the total material footprint (6.5 million tonnes) and corresponds to the consumption of products of the agrifood value chain (cereals, oilseeds, livestock and animal feed, for example) as well as timber and other bio-based materials. Finally, **metal ores**—flows of processed metals (such as steel and copper) that are closely linked to manufacturing and construction value chains—make up the smallest share of the material footprint (13%), totalling over 6 million tonnes.

The sectors contributing the most weight to Munich's material footprint reflect the overall economic structure of the city. The top ten productive activities (out of 200 analysed) contribute roughly 25 million tonnes, representing about 54% of Munich's total material footprint. Most raw materials are embedded in the construction sector, the manufacturing and consumption of consumer goods, services and, to a lesser extent, power and fuel consumption and agrifood activities. Looking at these main sectors, the largest contributor is **Manufacturing**, comprising various industries like motor vehicle manufacturing and clothing, electronics, furniture and many other goods, which, combined, have a total material footprint of roughly 19 million tonnes (41% of the total). This is followed by **Construction**, with activities such as building work and real estate services that account for over one-fifth (21%, or 10 million tonnes) of the total material footprint. **Services**, including a mix of activities from the tertiary sector and essential public services such as public administration and defence, health and social work, and education, contribute almost 8 million tonnes, or about 16% of the total material footprint. **Agrifood**, in particular activities such as the production of food items like fresh fruit and vegetables, dairy and other food products, and energy (production of electricity and the distribution and supply services), are responsible for much smaller shares of the total material footprint (9% and 7% respectively). This dynamic reflects a rather typical economic structure of an industrialised and affluent society like Munich, a large urban area in which material-intensive activities such as the manufacturing sector and the built environment drive an important share of material consumption and also in which tertiary economic activities such as various services also play a key role at the local and national scales.

CARBON FOOTPRINT

Measuring the material footprint of a city is not enough to fully gauge its environmental impact. While the material footprint gives insight into the impact of material consumption at home and abroad, assessing the carbon footprint is equally essential. Cities are responsible for over 70% of global GHG emissions, about 70% of which are tied to material use and handling. Therefore, the circular economy and climate agendas are inherently intertwined—and cities will be at the forefront of this challenge.[76] Consumption-based carbon footprinting can be used to measure the GHG emissions generated by the consumption of goods and services in cities. By accounting for the emissions embodied in imports and exports, carbon footprinting can provide a more accurate picture of an urban system's contribution to global emissions, compared to production-based accounting. This can help identify opportunities to reduce emissions and improve environmental performance.

EMISSIONS ACCOUNTING, CARBON FOOTPRINTS AND GERMANY'S BISKO STANDARD

In Germany, the BISKO standard, short for *Bilanzierungssystematik kommunal*, is a **territorial-based** methodology for standardising GHG balances at the municipal level. This systematic accounting approach provides a comprehensive framework to consistently record, measure, report and compare carbon accounting for German municipalities.

So, why don't we use the BISKO standard when analysing Munich's emissions profile? Like with the material footprint, every *Circularity Gap Report* takes a life-cycle approach to quantify the environmental impacts of material consumption.

Unlike BISKO's territorial-based methodology, this report uses a **consumption-based** carbon approach when accounting for GHG emissions. Both approaches are science-based, robust, widely-accepted methodologies, used in different contexts, as they present differences in geographical focus, scope and application. Consumption-based GHG emissions footprinting accounts for emissions from goods and services consumed by the residents of a locale, regardless of where those emissions are released. This can include emissions produced globally that are associated with local consumption. The broader scope includes all emissions related to consumption, including those outside the geographic boundaries due to imported goods and services. The main advantage of this approach is that it can be used to track emissions embedded in the global supply chains of products and services consumed at various scales, from individuals to cities to countries.

In 2019, Munich's total carbon footprint was 34 million tonnes of CO_2e, equivalent to **23 tonnes per capita, of which 88% (around 30 million tonnes of CO_2e) is generated beyond the city's boundaries.** This exceeds the national average carbon footprint per capita (14 tonnes of CO_2e) by almost two-thirds (62%), and is almost two and a half times the footprint of the average EU citizen (10 tonnes of CO_2e). Of the total carbon footprint, only 12% (4 million tonnes of CO_2e) stems from direct emissions, which reflect the emissions associated with direct household consumption activities. Land use, land-use change and forestry (LULUCF) emissions (-0.3 million tonnes of CO_2e), and imports from other parts of Germany and the rest of the world make up the remaining and largest shares of the footprint (45% and 43%, respectively). This was calculated through a consumption-based approach and using a life-cycle perspective. Only accounting for direct emissions would provide a flawed and largely underestimated impression of the total impact generated by Munich's high rate of consumption.

Manufacturing, Services and Construction are the biggest contributors to Munich's carbon footprint. The top ten productive activities (out of 200 analysed) are responsible for 42% of the total carbon footprint, with 15 million tonnes of CO_2e emitted annually. Diving deeper into the sector groups, **Manufacturing activities are the largest single contributor to Munich's carbon footprint**, representing about 32% of the total (11 million tonnes of CO_2e). Most of this can be attributed to carbon-intensive activities such as the production of Motor vehicles, Furniture, Machinery and equipment, Wearing apparel and many others—revealing the impacts of a highly industrialised metropolitan area in which important energy-intensive multinational manufacturing companies play a major role. Different **Services—both commercial and public—account for the second most important source of emissions** within the total footprint, representing 23% of the total (around 8 million tonnes of CO_2e)—combining activities from the tertiary sector but also public services such as Public administration and defence, Social security services, Cultural and recreational services, and Health and social work. **Construction is the third largest contributor** to Munich's carbon footprint, representing 14% of the total (around 5 million tonnes of CO_2)—including Construction work, construction waste reprocessing, and Real estate activities. Other smaller contributing sectors include **Energy**, from which the production, distribution and supply of electricity and heating to Munich's end-users account for around 8.4% of the total (3 million tonnes of CO_2e), **Agrifood** (also 8.4% of the total at 3 million tonnes of CO_2e), and **Mobility** (6% of the total, at 2 million tonnes of CO_2e).

THE BUILT ENVIRONMENT CAPTURES THE BULK OF MUNICH'S 'HIDDEN' ENVIRONMENTAL IMPACTS

In addition to construction activties' material and carbon footprints, the Built environment has a hidden, indirect role in concentrating the city's total environmental impacts. As a key feature of urban space, the Built environment determines the way in which cities function and encompasses several of the most material- and carbon-intensive activities. For example, a large share of the materials consumed by Services—both commercial and public—result from the consumption of construction material (such as non-metallic minerals and metals) and fossil fuels for heating in different commercial (such as restaurants, hotels and office spaces) and public (such as hospitals, schools, and administrative offices) buildings. The same applies to their respective carbon footprints: they are almost directly correlated to material consumption and are a result of the combustion of fossil fuels for heating.

Similarly, part of the material consumption and emissions associated with 'Electricity and Gas' comes from the interlinkages between the energy system and the Built environment. On the one side, this entails the existence of a complex and interconnected energy infrastructure (transmission and distribution equipment, transformers, voltage regulators, circuit breakers), which demands a significant amount of materials for energy to reach end customers (domestic, commercial and municipal establishments). On the other side, electricity, especially heating, is currently responsible for a substantial share of direct GHG emissions (especially from gas and coal combustion).

Combining impacts from the Construction sector and a significant part of Services activities as well as energy distribution to end consumers, **the Built environment is revealed as the single biggest contributor to Munich's material footprint and the largest source of total (direct and indirect) GHG emissions. This is, therefore, the single most important area in which to focus to reduce Munich's environmental impacts.**

3

METRICS FOR CIRCULARITY: MEASURING THE CIRCULARITY OF MUNICH

Munich's Circular Indicator Set

Measurements are critical to understanding the world around us. In 2018, Circle Economy Foundation started measuring the state of circularity of the global economy in its first edition of the global *Circularity Gap Report*. This approach has since been adapted to suit national and regional contexts.[77] This novel edition of the *Circularity Gap Report* now extends this approach to evaluate a city's circular economy state. Before taking action towards a circular economy, one of the first steps for cities is to understand their starting point as the foundation for informed decision-making.[78] This chapter dives into the methodology used to assess Munich's circularity and introduces a set of indicators that shed light on critical material flows contributing to the city's large material and carbon footprints. These insights offer an initial assessment, enabling the identification of circular opportunities and helping prioritise impactful material flows, which, in turn, can inform strategic plans to enhance circularity. This measurement approach allows local stakeholders to track circular performance over time, establish consistent goals and targets, and guide future action in the most impactful way.

HOW WE MEASURE CIRCULARITY

To measure circularity, we use the metabolism of the urban economy—the way in which materials flow through a city's economy and are used over the long term—as the starting point. This approach builds on and is inspired by the work of Haas et al.[79] (2015) and is a down-scaled adaptation of the national and regional approach of the *Circularity Gap Reports*. Taking an 'X-ray' of the economy's material use, we consider six fundamental dynamics of what the circular economy transition aims to establish and how it can do so. This translates into two objectives and four strategies based on the work of Bocken et al. (2016).[80]

The core objectives are:

- **Objective one:** Resource extraction from the Earth's crust is minimised, and biomass production and extraction is regenerative, meaning that it contributes to ecosystem preservation and restoration;
- **Objective two:** The dispersion and loss of materials is minimised, meaning all technical materials have high recovery opportunities, ideally with minimal degradation and with optimal value retention; emissions to air and dispersion to water or land are prevented; and biomass is optimally cascaded.

The four strategies we can use to achieve these objectives are:

- **Narrow flows—Use less:** This approach involves decreasing the consumption of materials, including fossil fuels, by productive activities while still satisfying the societal needs of an economy. This can be achieved through circular design or increasing the utilisation rates of materials and products. Practical examples include climate-smart urban planning, sharing and rental models, material lightweighting (mass reduction) in production and construction processes, multifunctional products or buildings, energy efficiency, digitisation and more.
- **Slow flows—Use longer:** This approach focuses on optimising resource use by extending the functional lifetime of materials and products. It can be achieved via design for durability, repair and remanufacturing, and all other activities that can contribute to slowing rates of extraction and use. Practical applications include modular building design, renovation and remodelling over building new structures, and second-hand consumption of textiles, furniture and electronics, for example.
- **Regenerate flows—Make clean:** In this approach, virgin raw materials, fossil fuels, pollutants and toxic materials are replaced with regenerative alternatives, thereby increasing and preserving value in natural ecosystems. Practical implementations of this include using regenerative and non-toxic materials for building renovation and new construction, transitioning to renewable energy sources, and adopting regenerative practices in urban farming and nature-based solutions.

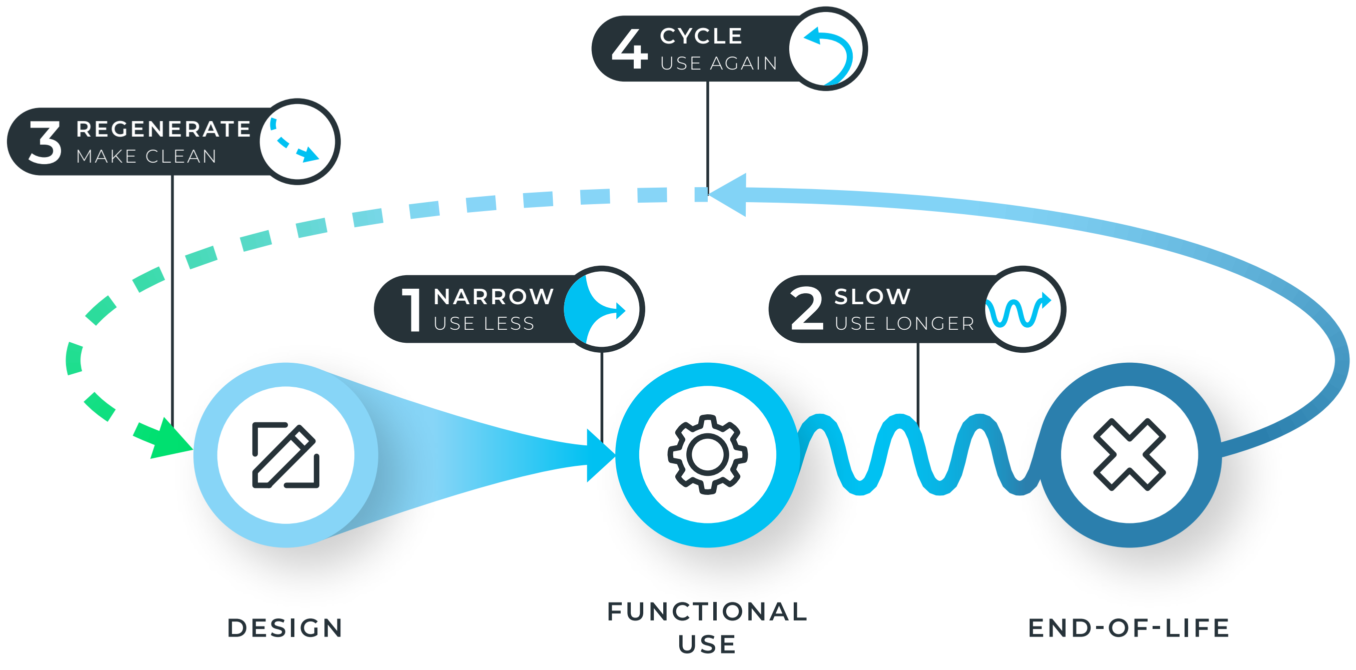


Figure three depicts the four strategies to achieve circular objectives: narrow, slow, regenerate and cycle.

- **Cycle flows—Use again:** This strategy emphasises the optimisation of reusing materials and products at end-of-life, facilitating a circular flow of resources. It involves improved collection and reprocessing of materials, along with optimal cascading, by creating value in each stage of reuse and recycling. Practical applications include designing for recyclability (both technical and biological), disassembly, and advanced (re)cycling technologies for construction and demolition waste and organic waste, for example.

While these four strategies are important, their deployment may lead to potential overlaps or even anti-synergetic effects. For more information on how these strategies affect each other in practice, refer to Appendix B on page 103.

DYNAMICS INFLUENCING HOW WE MEASURE CIRCULARITY

Understanding the current status of the global circular economy is relatively simple, largely because there are no exchanges of materials in and outside of planet Earth. For smaller-scaled systems such as countries and cities, however, trade dynamics introduce complexities to which we must adapt our calculations, resulting in certain methodological choices.[81] These are:

1. **We take a consumption-based perspective.** This means we only consider materials consumed within Munich, and allocate responsibility to consumers by excluding exports. Essentially, it accounts for the ecological impacts of the local population based on what they consume, regardless of where the goods and materials are processed and produced.
2. **We use demand-based indicators.** This approach reallocates the environmental stressors or impacts from the producers (those who manufacture goods) to the final consumers (those who buy and use goods). By doing this, the method ensures that resource depletion is allocated to economies that drive production through their consumption. In other words, it considers the impact on the environment caused by the demand for products and services in a particular area, regardless of where those products are actually produced.
3. **We consider both imports and exports in terms of their Raw Material Equivalents (RMEs).** This allows us to assess the true impact of finished and semi-finished products more accurately. Additional information on the concept of RMEs can be found on page 101.
4. **In addition to secondary materials recovered locally, we also consider secondary materials imported from abroad.** With this approach, we give 'credit' to cities for reducing virgin materials extraction by either processing secondary materials (recovered from former 'waste') locally or importing them from abroad.

For a more detailed explanation of these choices, please refer to Appendix C, on page 104.

INSIDE MUNICH'S CIRCULAR INDICATOR SET

To fully grasp the current status of circularity in Munich, we created a Circular Indicator Set considering all types of inputs into the urban economy: **Circular inputs** such as secondary materials and carbon-neutral biomass and **Linear inputs**, including fossil fuels and non-recycled materials, as well as **Stock build-up**.

This allows us to further refine our approach to closing the Circularity Gap in a particular context and answer more detailed and interesting questions: ***how much biomass extracted domestically (in Germany) is Munich consuming, and is it sustainable? How dependent is Munich on imports from other countries to satisfy its population's basic societal needs? How much material is being added to Munich's stock, like buildings and roads, every year?***

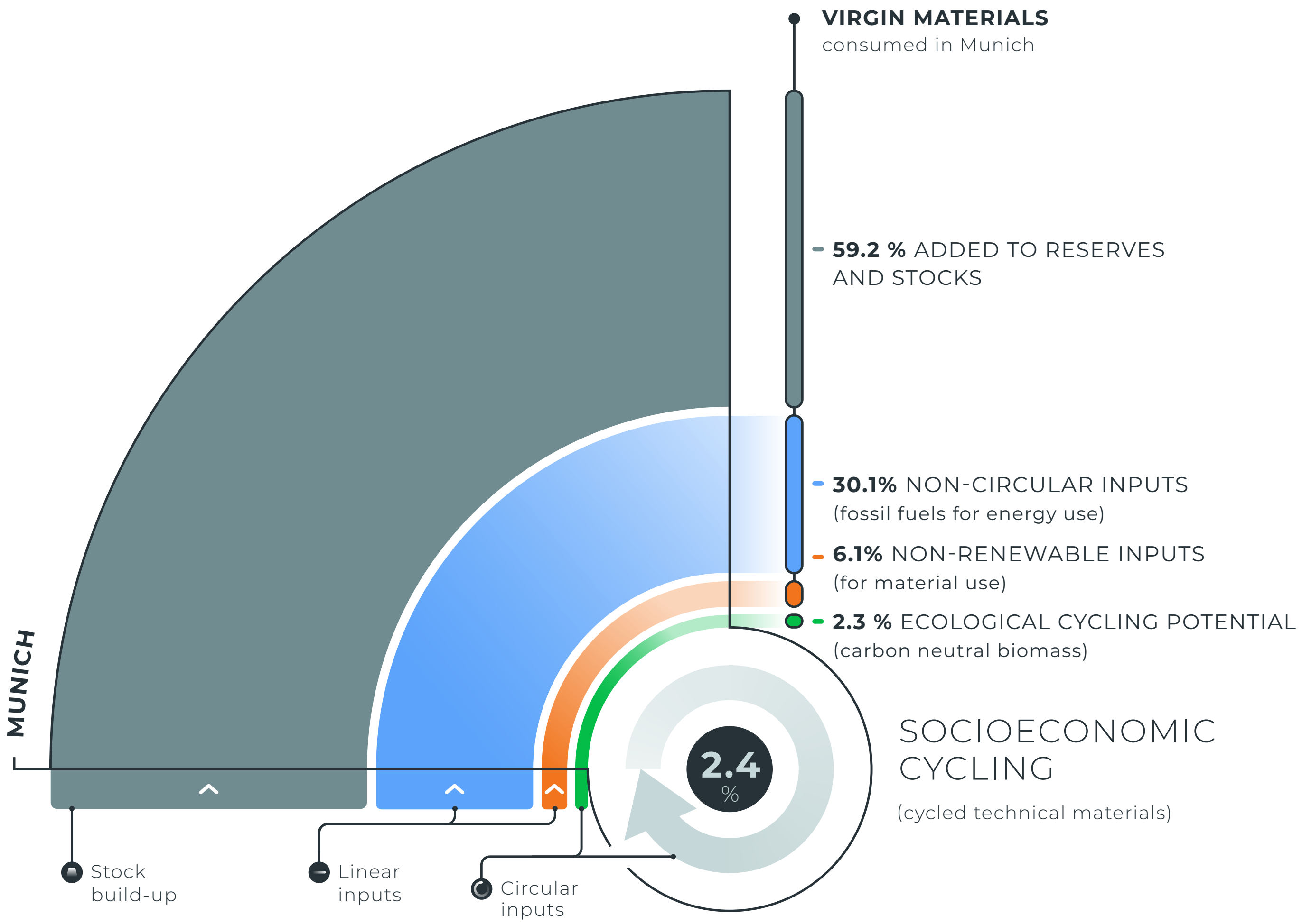


Figure four shows the full picture of circular and linear material inputs as well as stock build-up that make up Munich's Circular Indicator Set.

CIRCULAR INPUTS

Socioeconomic cycling (2.4%)

Socioeconomic cycling is what we sometimes refer to as the 'Circularity Metric'. It refers to the share of secondary materials out of the total consumption of an economy—in this case, Munich's urban economy. It accounts for all materials that were formerly waste but are cycled back into use, including recycled materials from both the technical (such as recycled cement and metals) and biological cycles (such as paper and wood). Socioeconomic cycling in Munich stands at 2.4%, below the global level of 7.2%.[82] In Munich, over half of secondary material consumption comes from construction and demolition waste being reused as aggregates in asphalt and concrete production (0.73 million tonnes out of 1.15 million tonnes).

Ecological cycling potential (2.3%)

Ecological cycling potential captures the share of biomass over total material consumption. Biomass *products*, such as paper and wood, are included in socioeconomic cycling, or the Circularity Metric. Meanwhile, ecological cycling concerns *primary* biomass such as trees, manure, food crops and products, or agricultural residues flowing through an economy. To be considered ecologically cycled, biomass should be wholly sustainable and circular. This means that it must, *at the very least*, be carbon neutral and guarantee full nutrient cycling—allowing ecosystems to maintain their biocapacity levels. Because detailed data on the sustainability of primary biomass is unavailable, to estimate the ecological cycling potential in Munich, we can look at the overall carbon balance of the economy's biomass. If the amount of carbon emitted by Land Use, Land Use-Change and Forestry (LULUCF) activities within Germany is equal to the amount of carbon 'absorbed' by the economy through primary biomass consumption, then all consumed biomass could be considered carbon-neutral. In Munich, all biomass falls into this bracket.

MUNICIPAL SOLID WASTE GENERATION AND TREATMENT IN MUNICH

In 2019, Munich's households and commercial establishments generated almost 720,000 tonnes of municipal solid waste (equivalent to 467 kilogrammes per capita per year), 79% of which came from households, and the rest from commercial, industrial and institutional establishments.[83] The largest fraction of collected waste is residual mixed waste (43% of the total municipal solid waste collected), recyclable materials separated at home by households (such as glass, paper and plastic), other recyclable waste (such as green waste from industry, household organics and construction site waste) and bulky waste. General figures show a rather high recycling rate in Munich (53%), including 275,000 tonnes of materially recycled waste, 76,000 tonnes recovered biologically and 3,500 tonnes prepared for reuse. However, a substantial amount of waste (462,972 tonnes) is still incinerated in Munich, particularly at the HKW Nord facility.[84] While the facility is fitted with energy recovery technology (power and heat recovery), incineration is considered the least preferred waste treatment pathway from a circular economy perspective,[85] and results in the loss of valuable materials. Of the total waste incinerated in 2019, nearly 20% could have been recycled, thus contributing to higher circularity.

DIFFERENCES BETWEEN ECOLOGICAL CYCLING POTENTIAL AND SOCIOECONOMIC CYCLING

While carbon neutrality is a necessary condition for biomass to be considered sustainable, it is not sufficient in itself: other nutrients, such as nitrogen and phosphorus, should be fully circulated back into the economy or the environment. As of yet, methodological limitations exist in determining nutrient cycling—how energy and matter contained in biomass flowing through an economy is transferred back to other living organisms. To this end, in line with past Circularity Gap Reports, we have excluded ecological cycling in our calculation of Munich's Socioeconomic cycling metric, even though this could potentially boost the metric to almost 5%. For all economies, we take a precautionary stance with its exclusion, knowing that its impact on the cycling rate may not be accurate. For example, we cannot track biomass extracted in Munich to its final end-of-life stage, so it isn't possible to prove that the nutrient cycle has closed. If this were the case, however—and if sustainable biomass management were to become the norm—Munich's Socioeconomic cycling metric could significantly increase.

LINEAR INPUTS

Non-renewable inputs (6.1%)

Non-renewable inputs include things like metals, plastics and glass found in everyday products. They do not include fossil fuels or non-cyclable ecological materials, but only those that can potentially be cycled but are currently not (both in Munich and abroad). Munich's non-renewable input rate stands at 6.1% (nearly 3 million tonnes). This means that Munich could increase its circularity by improving recycling processes through measures such as increased separation of waste streams and by improving processes throughout supply chains and production processes happening abroad or in other parts of Germany to meet the demand for materials and goods in Munich.

Non-circular inputs (30.1%)

This category centres on fossil-based energy carriers, such as gasoline, diesel and natural gas. These fuels are burnt mainly for energy and, to a lesser extent, to produce chemicals and plastics. As they burn, they release GHG emissions into the atmosphere that are inherently non-circular. Here, circular economy strategies such as cycling are not applicable as the loop cannot be closed on fossil fuels—although the circular transition will inherently reduce emissions through 'narrow' and 'regenerate' strategies. At roughly 30%, or almost 15 million tonnes of fossil fuels consumed, Munich's non-circular input rate is particularly high, highlighting the still very fossil-dependent character of the city's economy, especially in the use of oil to power transport and natural gas for residential space heating, electricity generation and industrial processes.

STOCK BUILD-UP

Net additions to stock (59.2%)

The vast majority of materials that are needed to meet the urban population's societal needs feed into goods and products that remain in use for a relatively long time, like buildings, machinery and vehicles. These materials are 'added' to the reserves of an economy and are therefore referred to as Net additions to stock. They are key features of the urban landscape and form a direct connection between basic services and the flows of materials and energy, making them a primary determinant of material flows in cities. At roughly 59.2% of total material consumption, Munich's **per capita stocking rate** stands at 19.5 tonnes per person per year. This is significantly higher than the global average of 4.5 tonnes per person per year. To boost circularity in Net additions to stock, it is possible to prioritise durable and sustainable design, enhance deconstruction and recycling processes for ageing assets, and encourage reuse and refurbishment practices. However, building, maintaining and refurbishing these stocks can also require significant amounts of materials and energy. The configuration and quantity of these stocks are crucial factors in determining material demand, future waste flows and (re)cycling potential.

STOCKS AND FLOWS: IF CONTINUED STOCK BUILD-UP IS INEVITABLE—SHOULD IT BE CONSIDERED PART OF THE 'GAP'?

Many of the raw materials used worldwide accumulate in stocks, such as buildings, infrastructure and machinery. Stocks form the physical infrastructure to provide vital services such as shelter, mobility and communication in any city. This stock build-up is not inherently bad; material stocks are essential for societies and economies to function and are a prime example of how materials are used to provide social benefits. However, these materials remain locked away and are not available for cycling—therefore weighing down the Socioeconomic cycling metric.

For Munich, stock build-up will be necessary to meet the demand for new, decent and affordable housing and public services from the steadily growing urban population and to support the continuous expansion and development of renewable energy and transport infrastructure. For these reasons, it may be argued that 'Net additions to stocks' should not be considered part of the Circularity Gap. If all the materials locked into stock were not considered part of the full Indicator Set, the Socioeconomic cycling metric would increase substantially. By employing circular strategies, such as circular design and lifetime extension, we would expect to see the rate of stock build-up decrease.

Nevertheless, the Socioeconomic cycling metric is ultimately a measure of what is cycled—not just what is circular—and materials added to stock are potentially locked for decades, if not more, during which they cannot be recovered and cycled. What's more, the circularity of materials added to stocks cannot be ensured: it is not always clear which portion of these materials are designed and used with cycling in mind or to which extent they are regenerative and non-toxic, for example. The bottom line is that the built environment consumes a huge volume of materials: its impact on Munich's overall consumption should not be ignored, especially given crucial resource depletion and decarbonisation concerns. The role of circular strategies in optimising Net additions to stock for circularity—and decreasing material consumption overall—is critical, as it helps reduce total material demand as well as waste and emissions generation in a circular economy.[86]

PRACTICAL CHALLENGES IN QUANTIFYING CIRCULARITY

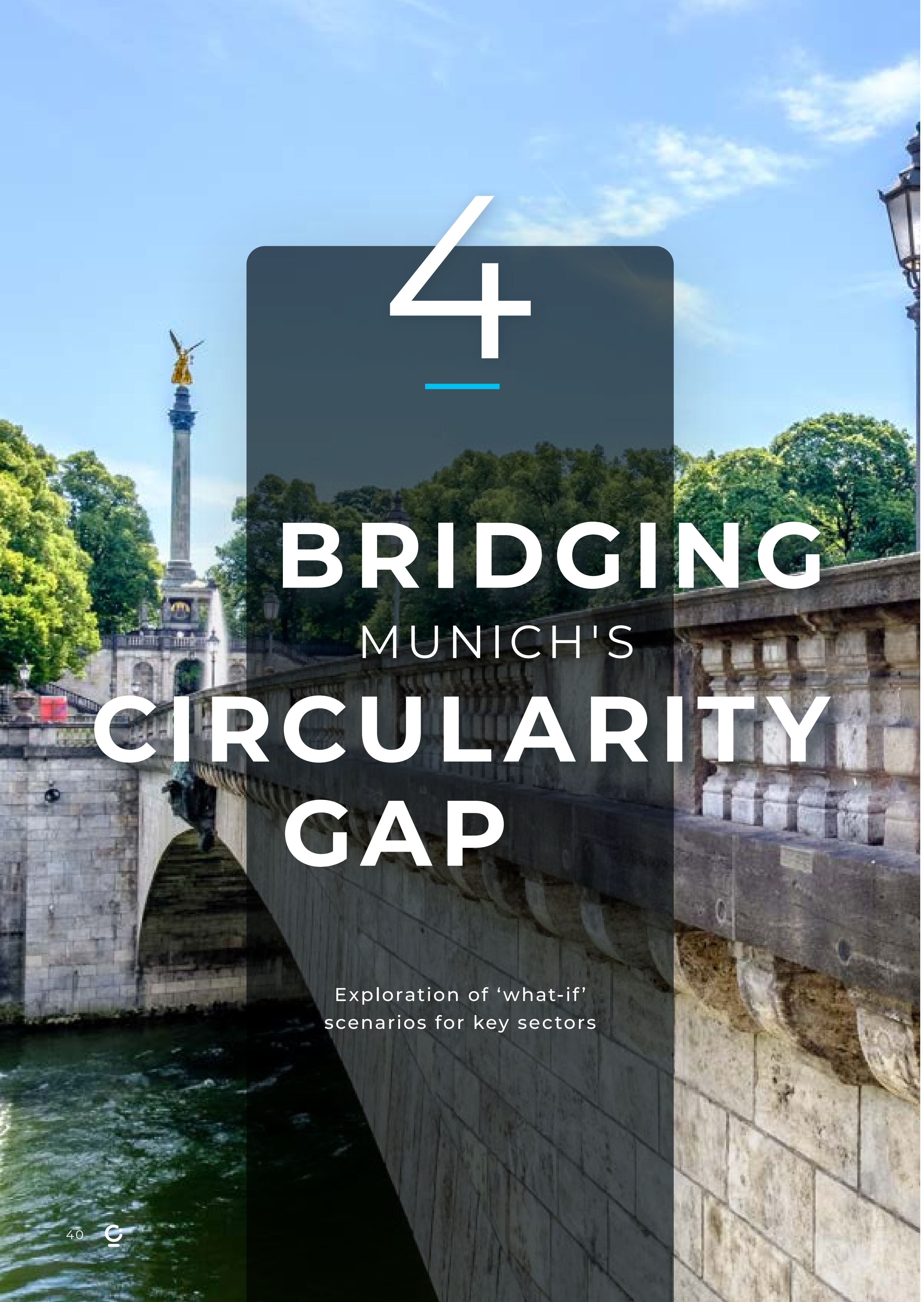
Providing a year-zero baseline measurement of the circularity of an economy based on material flows offers many advantages, not least that it can be used as a call to action. However, the circular economy is full of intricacies, and therefore, simplifications are necessary, which result in limitations that must be considered. The results for Munich illustrate several of the complexities of analysing the 'circularity' of an urban system:

- **Measuring circularity requires more than a single indicator.** Using less, using longer and regenerating natural systems are all principles that complement the idea of 'closing the loop', which is most commonly associated with the concept of circular economy and captured by a single indicator: Socioeconomic cycling. By focusing on a broader Circular Indicator Set, we can provide a more comprehensive and accurate assessment of the status of the circular economy and its potential impacts.
- **There is more to circularity than (mass-based) cycling.** As seen from the examination of the four flows, circularity has other important aspects: using less, using longer and regenerating natural systems. Our analysis captures these in other ways: using less, for example, is captured by decreases in the material footprint while regenerating natural systems could materialise as fewer non-circular inputs and, therefore, a decrease in the carbon footprint. This means that, despite the fact that Munich may show high separate collection and recycling rates on municipal solid waste, as well as in certain industrial and commercial waste streams like construction and demolition, this is low compared to the sheer amount of total materials consumed across the entire life cycle of products, contributing to a relatively low socioeconomic cycling indicator.[87]
- **Socioeconomic cycling only focuses on one aspect of circularity.** We focus only on material use without examining other factors such as biodiversity loss, pollution, toxicity, et cetera. This reveals the limitations of focusing solely on materials' cycling or on the 'closing-the-loop' effect. Socioeconomic cycling is calculated as the share of secondary materials (numerator) over the total consumption of the urban economy (denominator). In a system with high total material consumption like Munich, increasing material cycling has a much smaller impact on the overall material cycling indicator: the bigger the denominator, the smaller the impact of increasing the numerator is on the overall percentage. This also means that in consumption-driven economies, it is not only important to increase material cycling but also to decrease consumption in order to increase the percentage metric significantly.
- **We consider relative, not absolute, numbers.** This means that if cycling increases faster than material consumption, the Socioeconomic cycling metric will improve—even if the ultimate goal is for material demand to decrease.
- **Achieving 100% material recirculation isn't feasible, nor should it be an objective.** Cycling has technical and practical limits, and some materials will always be required for stock build-up. Other materials, like fossil fuels, are also inherently non-circular and cannot be cycled. Material recirculation is only one of the levers that can be employed to achieve the ultimate goals which are to bring Munich's material footprint closer to global sustainable averages. However, other circular action mentioned at the beginning of this chapter will be as important, if not more, in achieving this.

For more detail on each of these points, please refer to Appendix D, on page 105.

CHALLENGES FOR MEASURING MATERIAL FLOWS AT CITY LEVEL

The *Circularity Gap Report Munich* is a pioneering attempt at conducting an economy-wide circularity assessment in an urban context. This meant the development of an innovative methodology, based on Circle Economy Foundation's experiences from previous *Circularity Gap Reports* (see the Methodology document), downscaling the approach from a national analysis to a city-level analysis. One important challenge was the accurate tracking of materials entering and leaving Munich. This is because city boundaries are much more 'open' than those of a nation and because local capacity for data collection is also more limited than on national or state level.[88] Where data were only available at greater geographical scopes, such as on the level of Bavaria or Germany, we employed various downscaling techniques. These were parameterised using bottom-up data that was compiled from different Munich-level economic indicators such as the gross value added (GVA) of economic sectors, household expenditures, and of course, Munich's population, in relation to the state or national level. While these proxies made it possible to gain insights into the sizes of most material flows, the precise tracing of their destination, and their treatment at end-of-life both within and outside national borders remains challenging.



4

BRIDGING MUNICH'S CIRCULARITY GAP

Exploration of ‘what-if’ scenarios for key sectors

After understanding the current status of circularity in Munich—deep diving into the city’s material and carbon footprints, presenting the Circular Indicator Set and investigating the key themes of the economy—we can now explore pathways towards a more circular Munich. In this chapter, five scenarios across key sectors explore the ‘what-if’, ultimately sketching a future for a more circular Munich that’s resource-light, low-carbon and wellbeing-focused. These scenarios explore a potential way forward for Munich, outlining which sectors and interventions could be the most impactful in reorienting the city’s material and carbon footprints and increasing secondary material consumption.

BRIDGING THE CIRCULARITY GAP: 'WHAT IF' SCENARIOS

Circularity Gap Reports’ scenarios have been largely free from the constraints of law or political realities: **using 2019 data as a baseline year**, the scenarios in this chapter are deliberately non-time-specific and exploratory: the complexities of their real-life implementation did not inform the analysis. Through this approach, we can freely imagine what our society could look like with truly transformational change. Below, we present five scenarios, outlining different types of interventions that allow us to 'dream big' and sketch which type of levers are most impactful in reducing the material and carbon footprints.

We have funnelled our focus for the ‘what-if’ scenarios into five key material and carbon-intensive systems that represent key leverage points for Munich’s socioeconomic metabolism. These scenarios are:

1. **Build a circular built environment**
2. **Shift to a circular food system**
3. **Advance circular manufacturing**
4. **Promote a circular lifestyle,** and
5. **Redesign mobility.**

We focus on a few key sectors to thoroughly assess and pinpoint the most effective circular interventions in Munich. These interventions roll out technological and socio-cultural changes to ultimately reduce the material and carbon footprints. However, this analysis does not fully capture all potential environmental impacts. For this reason, this chapter also reports on the additional environmental, social and economic co-benefits of each scenario’s chosen circular interventions—contributing to the dynamic debate on where to place our bets for enhanced circularity and reduced consumption in Munich and other major cities worldwide.

The impacts of the scenarios and their corresponding interventions on Munich’s economy are measured in terms of changes to the material and carbon footprints. The selection of scenarios was based on quantitative and qualitative research, which aimed at providing an outline of what is possible to model, considering methodological limitations. The modelling capacity behind the Circularity Gap Methodology is continuously evolving and improving—reflected by the approach in this report—and will continue to improve for future editions. Refer to the Methodology document for more information on this project’s scenario modelling. All assumptions behind the modelling of these scenarios can be found in Appendix F, on pages 107–110.

The scenarios are informed and developed by the ultimate aims of **slowing, narrowing, cycling and regenerating** material flows, as described on page 32, which provide a jumping-off point for the strategies needed to spur systemic changes.

1. BUILD A CIRCULAR BUILT ENVIRONMENT

Globally, the impact of the built environment is enormous: construction and operation activities account for approximately a third of material consumption, carbon emissions and solid waste generation worldwide.[89, 90] As the global urban population increases,[91] how we build and construct cities will become key to mitigating the environmental impacts of all activities related to the built environment.[92] At the same time, buildings are huge banks of reusable materials, and their design and construction are fundamental in determining the amount of materials that may become available for reuse in the future. For all these reasons, when looking at city-level dynamics, it is essential to understand how to better use materials available within the built environment—in particular, in building stocks. This understanding will equip decision-makers with the necessary tools to help them minimise material demand, embodied energy and emissions, and waste generation from the built environment system.[93]

URBAN PLANNING AND DEVELOPMENT

Urban development is a crucial target area in which to reduce material consumption of the built environment and its associated environmental impacts.[94] In Munich, endeavours must be made to work with existing building stock as much as possible: many of the materials needed for future use are currently locked into finished buildings.[95] For a circular economy to be realised in Munich, the development and planning of the built environment must safeguard public interests and embrace and foster a circular building culture.[96] The municipality has a key role to play in this regard. Through its *Urban Development Plan for 2040*, Munich focuses on six fields of action and identifies synergies to adapt to a steadily growing population and develop a more balanced, affordable and sustainable city.[97] The main goals, strategies and measures include 1) Green and networked open spaces, 2) Efficient, reliable and climate-neutral mobility, 3) Strong residential areas and sustainable urban development, 4) Climate-adapted landscape and settlement areas, 5) Climate-neutral districts and renewable energies, and 6) Partnership development of the urban region.[98] Achieving these requires a substantial mobilisation of resources, including financial, which is reflected in the investments that the city has planned in housing and construction between 2021 and 2025 (amounting to a total of €1.65 billion).[99] This plan represents a major opportunity to advance circular building and planning practices in the built environment.

As the urban space continues evolving in Munich, the municipality will play a key role in making the best use of existing housing stock and new urban development measures. More broadly, introducing circular economy principles to promote resource-efficient building lifestyles within the city and new infrastructure—particularly around mobility options, local consumption and the use of private and public infrastructures—will be crucial. In fact, development projects are emerging to turn green courtyards into areas for new housing or even to add new floors to existing buildings to avoid using more land surface, for example.[100] While these actions tend to increase the density of housing spaces,[101] the city is also increasing liveability by carrying out modernisation efforts in public squares. Recent developments also show that topics such as pedestrianisation and the greening of urban zones are becoming part of Munich's urban planning agenda.[102]

CONSTRUCTION

Construction is a major (and growing)[103] economic activity in Munich that contributes significantly to the city's economy and employment.[104, 105] Construction is also a major driver of primary raw material consumption and waste generation in the city. Construction activities alone claim over one-fifth (21%) of the total material footprint, particularly mass-heavy and carbon-intensive materials such as concrete and steel. What's more, the construction sector is highly waste-intensive and resource-inefficient. In Germany, over 200 million tonnes of construction and demolition waste (C&DW) is generated every year,[106] with Bavaria alone producing 53 million tonnes in 2018. The circular economy can play a key role in delivering growing demand for new, more innovative and environmentally friendly products and production methods, but the ability to deliver will require rethinking how the construction industry operates and where materials are sourced.[107] Within this context, circular public procurement is a key tool to generate enabling market conditions for circular business practices that reduce the use of virgin high-impact construction materials, particularly concrete and steel (see the text box on page 46).

To this end, this scenario comprises three interventions that explore how the city of Munich can:

1.1 **Optimise building stock expansion and increase occupancy rates**

1.2 **Shape a low-carbon, energy-efficient building stock,** and

1.3 **Shift to resource-efficient building processes.**

1.1 OPTIMISE BUILDING STOCK EXPANSION AND INCREASE OCCUPANCY RATES

The first intervention targets the construction sector's material use through strategies that narrow material flows and **cycle** materials back into the economy at their end-of-life. Optimising new builds and increasing the reuse of building materials (steel, concrete and timber) and components (doors and window frames, for example) will reduce the demand for raw material inputs. At the same time, this intervention presents a range of strategies to optimise building occupancy rates, cutting the total number of new buildings needed—**slowing** and, ultimately, **narrowing** material flows.

Over 90% of the city buildings needed in Munich for the coming years have already been built. The construction of new buildings and homes has increased alongside Munich's growing population, which has led to an urban expansion around the city—first residential developments, followed by new commercial establishments on the city's periphery. In addition, the number of single-person households is on the rise,[108] and Munich's residents are increasingly looking for larger and more spacious apartments, especially as people are spending more time at home post-pandemic.[109, 110] This contributes to the fundamental housing shortage (as shown by the high housing occupancy rates) that Munich is experiencing.[111] As of 2021, the city counted nearly 965,000 houses.[112] About 40,000 new homes have been constructed since 2016,[113] and under Munich's housing construction programme, the city aims to build at least 8,500 new housing units every year. Meanwhile, housing in Munich is not becoming cheaper—the real estate market has experienced a sharp price increase, giving Munich the highest average building land prices in Germany.[114] Therefore, while construction is expanding in response to the growing need for accommodation, housing is becoming less affordable for citizens, sending a strong economic incentive for new and cheaper construction further away from the city centre, ultimately reinforcing the urban sprawling effect instead of circular decentralised neighbourhoods.

The circular use of construction and demolition waste in new construction

Secondary raw materials in cities like Munich harbour plenty of economic and environmental potential—there is room for improvement to unlock the high-grade sorting and processing of construction waste for high-quality applications in building construction.[115] Where new construction is needed, Munich could increase its use of secondary building materials, such as recycled concrete aggregate and recovered steel. The use of secondary materials in construction is still limited in Germany—less than 13% of materials consumed in the industry come from secondary sources, despite an increasing interest in using secondary resources in the future.[116] To do so, significant improvements in C&DW recycling are needed. Bavaria has the opportunity to develop a secondary raw materials market for the building industry, which holds great potential for material savings.[117] Out of the 53 million tonnes of C&DW generated in Bavaria in 2018 (predominantly excavated soil, stones, construction waste and road rubble), only 15.6% was sent for recycling and only 2% was actually used in new construction.[118] The vast majority was sent for low-value (downcycling) treatments such as backfilling activities, and pre-treatment for asphalt mixing or landfills.[119] One of the main barriers to the high-value recycling of C&DW is a lack of appropriate selective dismantling, sorting, and secondary material tracking and transparency practices.[120] Other major barriers are the unclear financial viability and limited economies of scale for C&DW recycling, which make primary raw materials far less expensive than recycled materials. Price is also the determining criterion for most German municipalities when putting deconstruction and new construction projects out to tender, whereas material circularity and sustainability are often overlooked.[121] To overcome this, experts suggest several measures, such as revising tendering criteria to introduce recycled material content and promoting circular construction (more detail on circular public procurement for construction is available in the text box on page 46). In addition, the possibility of introducing a raw materials tax, for example, on sand and gravel, would make the production of primary concrete more expensive and recycling more financially rewarding.

Urban mining

Urban mining is another potential solution for the local supply of alternative construction materials. Metals and construction minerals (sand, gravel and stone, for example) remain in infrastructure and buildings for a long time (the average lifetime of buildings in Munich and Germany lies between 50 and 100),[122] which means that the built environment accumulates significant stocks of materials that could, one day, become available as secondary materials for new construction purposes.[123] In addition, it has the advantage of 'urban mines' being located exactly where raw materials are needed: in cities.

1.2 SHAPE A LOW-CARBON, ENERGY-EFFICIENT BUILDING STOCK

This intervention comprises two strategies: deep retrofitting practices and the large-scale deployment of low-carbon energy management and heating technologies, such as heat pumps and smart metres. These will serve to **narrow** material flows, particularly fossil fuels. Retrofitting activities should use secondary and non-toxic materials to the greatest extent possible, **cycling** and **regenerating** flows. Material choice is important, as carbon embodied in certain materials may generate knock-on effects, counteracting benefits from improved energy efficiency.

Energy efficiency

Although energy standards are generally quite high in new buildings, the existing building stock and its low energy efficiency pose the greatest challenge in tackling building emissions. Like many European cities, a considerable share of the building stock in Munich is relatively old and has low energy efficiency.[124, 125] In Germany, the building sector accounts for 40% of final energy use and is associated with 30% of GHG emissions,[126] in particular due to the high use of fossil gas for heating. In Munich, 75% of buildings use natural gas for heating, followed by district heating (18%) and oil heating (7%).[127] Reducing energy demand from buildings, from private housing to commercial and public buildings, via deep retrofitting will be key to decarbonise Munich's building stock. However, to meet the City's target of reducing 0.3 tonnes of CO_2e per capita per year by 2050, efforts to decarbonise buildings will have to accelerate as only 1% of the housing stock is thermally upgraded every year.[128] This will require a mix of different technologies, innovative approaches and behavioural changes. While low-carbon, energy-efficient technologies such as heat pumps and solar photovoltaics will certainly be part of the mix,[129] the municipality is also investigating how the heating supply can be converted to renewable energies, for instance, through alternative options for energy generation such as deep geothermal energy capture, or the decentralisation of the energy generation structure.[130]

It is important to emphasise that energy efficiency also entails plans for more robust and integrated energy systems—increasing electrification and supporting more flexible renewable energy use, for example. That being said, energy efficiency measures typically target specific processes or products but may cause rebound effects that actually lead to larger total energy consumption. Therefore, energy sufficiency measures should also be integrated into buildings to address the use of floorspace, design and construction, and use of energy-consuming appliances. For example, simply setting thermostats lower can have a substantial impact on the energy consumed for heating and associated impacts.[131] Finally, finding urban-industrial synergies will also be key for harnessing available energy resources across sectors, between local industries and end-consumers to reduce (***narrow***) overall energy demand. Today, it is still too difficult to integrate excess heat from industrial activities to heat households or office buildings, for example. This means that Munich's true potential for energy efficiency improvements could be far greater than the effects calculated in this intervention, if all elements are considered.

1.3 SHIFT TO RESOURCE-EFFICIENT BUILDING PRACTICES

This Scenario's final intervention focuses on scaling material-efficient construction practices—thereby cutting material input and waste—to **narrow** flows while increasing the lifetime of bearing materials like steel, thus also **slowing** flows. Material choice is important, as embodied carbon in certain materials can counteract benefits from improved energy efficiency. Using bio-based construction materials such as wood can be an effective option to **regenerate** material flows in Munich's built environment. Material flows can be further **narrowed** through improved construction practices (for example, off-site construction). Incorporating circular design principles, such as modularisation and multi-purpose building, will extend the lifetime of buildings, thus slowing flows.

Building with alternative materials

In Munich, construction activities demand enormous amounts of raw materials throughout the value chain—16.8 million tonnes in 2019.[132] To move towards more resource-efficient and low-carbon building practices, the consumption of high-impact materials (steel and cement), which make up by far the largest share of the material footprint (and also GHG emissions[133]), can be reduced by prioritising alternative materials and building practices alongside prioritising secondary materials as much as possible (as mentioned in intervention 1.1). Renewable, bio-based construction materials like timber, flax and hemp could further become carbon stores over the lifetime of buildings if sourced from certified producers.[134, 135]

Circular architecture and design of buildings

By designing for circularity, architects can help reduce resource consumption, increase materials' longevity and facilitate the disassembly of parts and pieces. This includes design for modularity and for a flexible use of space, for example. Such design choices contribute to a wide array of benefits, such as reducing embodied carbon and virgin material use, reducing waste on building sites, shortening lengthy planning and construction processes (and associated costs), making the operational phases of buildings more efficient (in terms of energy consumption but also the use of space), and extending the useful lifetime of buildings.[136, 137] Circular design of buildings is still an uncommon practice—for example, modular buildings only make up 4% of Bavaria's market share.[138] However, this is likely set to change in the near future. For instance, designing for circularity in construction relies greatly on proof, certifications (Environmental Product Declarations) and the use of data to track material information (material passports and building information modelling, for example).

Making the construction value chain more circular will certainly be a complex process. A substantial change is needed across all steps of the value chain, from architecture and design to construction work, the supply of materials and components and C&DW handling. But it should also be seen as an opportunity for economic development, job creation and a way to create more affordable and sustainable housing quickly and cost-effectively in the future. The City of Munich has a key role to play in advancing a circular built environment for its residents and could support the process in many ways: beginning by changing policies regarding construction and C&DW management to ensure that good circular practices are incentivised, through permits for new construction, for example. The Municipality can also use legislative and other instruments such as tender approvals, handling permits and regulations to promote circular action. Cities can also influence stakeholders by promoting circular activities, such as incentivising life cycle thinking for materials, rolling out Extended Producer Responsibility schemes, and using circular public procurement for public tenders.

HOW CAN PUBLIC PROCUREMENT PROMOTE A CIRCULAR BUILT ENVIRONMENT IN MUNICH?

Municipalities are creators and re-modellers of urban environments.[139] They play a key role in adopting solutions and introducing circular economy principles in urban planning to best use existing buildings and infrastructure and promote resource-efficient lifestyles within the city, particularly around mobility and local consumption. One of the instruments that the City of Munich can use is **circular public procurement**.[140]

Circular public procurement can be a clear driver of circularity in cities and an 'incentive for public buyers to take a more holistic approach to sustainability'.[141] In an urban context, municipalities can lead by example and drive major sectors and businesses towards greater sustainability. Construction is an activity where the effectiveness of circular procurement is most evident—activities related to the built environment are among the most resource- and waste-intensive within cities. Therefore, construction procurement contracts have a very high potential for promoting circularity, in particular across the following pillars: Prevention of C&DW through planning, Extending building life cycles, Shifting towards a renewable and sufficient use of energy, Integrating system-level thinking and Recycling biological construction materials to the extent possible.

Munich has reasons and means to invest in new buildings and infrastructure projects and,[142, 143] **through procurement, create signals to prioritise investments** in circular construction projects.[144] Public procurement contracts can include:

- Circular criteria specifying the use of secondary materials in the requirements for new buildings and reduction targets for the use of new virgin materials, especially steel and concrete;
- Circular building design services;
- Utilities consumption efficiency (energy and water) in public buildings;
- Renovation and maintenance work;
- Investing in surveying and documenting existing building stock;
- Developing regulations and robust certification schemes for the reuse of secondary materials, especially where reuse for structural elements is concerned.

Good practice in circular construction procurement is becoming increasingly common, and there is a growing number of examples of cities managing to overcome the most common bottlenecks to circular public procurement (unclear and lengthy planning, lack of resources, lack of information and expertise). In particular, Munich can take examples from Nordic and Dutch cities such as Gothenburg, Copenhagen, Helsinki, Amsterdam, The Hague and others.[145]

WHAT PROJECTS ARE PLANNED IN MUNICH WHERE CIRCULAR PUBLIC PROCUREMENT COULD BE OR ARE BEING IMPLEMENTED?

- The new circular district at the Bayernkaserne (see text box on page 49).
- The main station is currently a major construction site: a new entrance building is being built to replace a terminal building that was demolished in 2019.
- The historic Hermann Tietz ('Hertie') department store is now being rebuilt in line with listed building regulations.
- The former Postbank site south of the main station is being redeveloped into the new Elementum residential quarter. The sustainable conversion envisages recycling the existing grey energy in the building by preserving more than 80% of the shell structure after gutting.
- The EU has selected the 'Neuperlach' venture as one of six New European Bauhaus (NEB) flagship schemes. The NEB is a cultural project that merges sustainability with inclusivity and aesthetics. The EU's Green Deal aims to implement it both with and for the people—and now it is also coming to Neuperlach. Incorporating aspects such as co-creation and entrepreneurship aims to turn the district into a sustainable innovation landscape.

IMPACTS

This scenario's three interventions have the highest overall potential to reduce Munich's material and carbon footprints. See a detailed breakdown of the impacts of each intervention in Table two below.

Building a circular built environment could bring many **co-benefits** beyond the environmental: retrofitting, for example, can serve to increase energy efficiency and cut energy consumption,[146] which in turn can increase resilience by reducing dependence on foreign materials, cut energy bills and costs for households and hedge against price volatility. Additionally, if designed strategically, retrofitted housing can help tackle multiple issues—from health inequalities to affordability—improving home standards, cutting costs and improving wellbeing. The same holds for modular design, as modular building parts and construction methods could become a quick and affordable response to the supply shortage the city is currently experiencing. Employing circular strategies for the built environment—such as off-site construction, using new materials and better material management, and renovation and retrofitting—can also spur job creation and create new business opportunities.[147, 148, 149, 150]

INTERVENTION	MATERIAL FOOTPRINT	CARBON FOOTPRINT
1.1 Optimise building stock expansion & increase occupancy rates	-13.2%, down to 41.8 million tonnes	-9.6%, down to 31.1 million tonnes of CO_2e
1.2 Shape a low-carbon, energy-efficient building stock	-4.9%, from 48.2 to 45.8 million tonnes	-7.9%, from 34.4 to 31.7 million tonnes of CO_2e
1.3 Shift to resource-efficient building practices	-3.7%, from 48.2 to 46.4 million tonnes	-3.3%, from 34.4 to 33.3 million tonnes of CO_2e
Combined scenario impact	**-18.3%, from 48.2 to 39.3 million tonnes**	**-17.3%, down to 34.4 to 28.5 million tonnes CO_2e**

Table two shows Scenario one's potential impact.

A CIRCULAR URBAN BUILT ENVIRONMENT IS ALREADY UNDERWAY IN MUNICH

Munich is already adapting and shaping the urban built environment using circular economy principles.[151] One of the best examples is the [new circular district at the Bayernkaserne](). Following the city's goal to establish circular building principles and within the scope of the European URGE project, a pilot project was launched to convert the 'Bayernkaserne' barracks—a former 50-hectare military site—into a sustainable 15-minute city and circular district with a modern urban design including apartments, schools, sports facilities, a park and more.

To maximise what has already been built and tap into principles like adaptive reuse, the City Council approved a recycling project that included on-site sorting and reprocessing of half of the 1.2 million tonnes of rubble available from the old military buildings. Consequently, the demand for virgin materials will be significantly lowered. Transportation needs will also be substantially lower, saving an equivalent of roughly 80 trips around the world. Part of the soil generated will also be used for horticultural and agricultural purposes, further minimising waste.

The project offers a fertile ground to overcome obstacles such as the lack of standardisation, practical knowledge, bureaucratic hurdles and other inefficiencies of working in silos. This new district can inform and inspire other projects, and different cities within and outside Germany have already expressed an interest in learning from it and embracing the opportunities of circular processes in the built environment.

Different organisations are now following the same direction. For instance, the Municipal Housing Association of Munich (GWG) stated its interest in establishing a circular built environment by including such principles in the development of the Ramersdorf district.

In this project, while the existing infrastructure is renovated or converted into modern energy-optimised buildings, the required raw materials are recovered from the existing infrastructure as much as possible.

Similarly, the Creating Neighbourhoods programme IS also working to reform an important area for Munich. This research programme belongs to the New European Building (NEB) framework and consists of an international network aiming to create environmentally friendly and future-proof neighbourhoods. The focus is on finding ways to make cities attractive, sustainable and affordable through the on-the-ground implementation and testing of different ideas. Circular thinking and collective action are emphasised as critical components in each project's design.

This process has been initiated for Munich-Neuperlach to transform the existing urban space of neighbouring city districts—approximately 1,100 hectares—following a sustainable urban planning vision. The area's urban regeneration is a priority for Munich and will be achieved by implementing circular practices in the built environment. Such practices include investigating alternative uses of space and materials and circular construction.[152] When Munich-Neuperlach's regeneration is complete, circular efforts will be complemented by actions related to ecology, energy efficiency and the creation of an improved social environment.[153] The results will support the establishment of circular buildings and practices, setting an example for other districts in the country and the rest of Europe.[154]

Drawing from all the acquired knowledge and lessons learned from these initiatives, it's time to scale up and formalise efforts to harness the city's full potential and achieve a circular built environment.

2. SHIFT TO A CIRCULAR FOOD SYSTEM

Cities greatly influence food systems, both within and beyond their physical boundaries. Most food is produced far from cities, yet they are the hotspots of food consumption. Indeed, the food system is a crucial element of any city and is intertwined with various aspects of the urban socioeconomic system, including health, businesses, culture and land use in peri-urban areas and beyond. Like all cities, Munich depends on imports from the rest of Germany and abroad to satisfy the demand for food products. In order to provide for its urban populations, more than half of the area of Bavaria is agricultural land, contributing to Germany's high agrifood production.[155] Agricultural production is well-known for its negative impacts on the local and global environment, as it not only contributes to climate change through methane and other GHGs,[156, 157] but also leads to nitrate pollution in air and water environments.[158] Aside from certain animal products such as beef, dairy, and some crops (such as potatoes and wheat), Bavaria and Munich are net importers of many agricultural and food products (for example, fresh fruit and vegetables).[159] As such, a substantial part of Munich's carbon footprint is embedded in imported food products. Therefore, it is essential to rethink Munich's food consumption habits and its worldwide impact on producing countries, in addition to local agricultural practices.

A more circular food system is one where agricultural production optimises the use of all biomass, regenerative production is prioritised, reuse and sharing practices are favoured, resource inputs and pollution are reduced, and resource recovery is ensured. It is also one where sustainable diets are the norm, and human health and communities' livelihoods are protected. Changes to the food system can range from farm to fork—from the production of crops or livestock on farms to the consumption of those products. This scenario looks at both. To cut Munich's food system's impact both domestically and abroad, we explore two main interventions:[160]

2.1 **Shift to more sustainable food production**

2.2 **Endorse a balanced diet,** and

2.3 **Reduce and valorise food loss and waste.**

These interventions are aligned with Germany's effort to reach the European Sustainable Development Goals, creating a sustainable and resilient food system and reducing nitrogen surpluses, expanding organic farming and reducing emissions from livestock farming, among other goals.[161, 162] In the context of organic farming, the goal for 2020 was to dedicate 20% of Germany's productive land to organic cultivation.[163] This scenario offers strategies that can place Munich on track to contribute to these goals.

2.1 SHIFT TO MORE SUSTAINABLE FOOD PRODUCTION

Shifting to organic, local and seasonal food production will regenerate and narrow flows by reducing the need for synthetic fertilisers, lowering transport distances and lessening dependence on foods grown in heated greenhouses, thus reducing fuel consumption for heating. While Bavaria's topography, climate and soil vary widely—making changes in agricultural practices challenging—we can envision a food production system that works alongside nature, protects biodiversity and cuts emissions and chemical inputs.

Organic farming

Agriculture is a significant driver of negative environmental impacts in Germany. This is largely because many of Bavaria's agricultural activities are still related to animal production and associated products, which are linked to high GHG emissions, land and water use, and deforestation. Roughly half of farms (47%) are engaged in animal production, 30% in arable crops and only 13% in mixed farming. However, the foundation for transforming the agricultural sector in Bavaria is already in place. Over recent years, the agricultural sector has undergone a structural transformation[164] in conjunction with evolving consumer habits. Germany is currently among the most advanced countries for organic farming and boasts the fourth-largest organic crop area and number of producers in Europe. Clearly, the shift from intensive agriculture to more sustainable methods has begun. Some positive results from this shift are already observable: nitrogen emissions and phosphate loads in soil dropped by approximately 50% and up to 25%,respectively, over four years.[165] Additionally, most open spaces or undeveloped areas around Munich are designated as green belt areas.[166] These areas cover approximately 70 kilometres, and their goal is to be used for agriculture and to create a balance between agriculture, recreation and nature preservation. The green belt areas are protected and managed ecologically to increase their quality in cooperation with local farmers and provide Munich with local products.

Urban agriculture

Munich is taking steps towards promoting urban agriculture to increase the city's independence and sustainability. Around 50,000 Munich residents cultivate products in various community gardens, most of which are open to the public. Additionally, many residents grow vegetables and fruits on their balconies and in private gardens.[167] Munich offers space for ecological gardening and agriculture despite the increasing urban density.[168] Several initiatives are in place to support urban gardening, raise awareness and promote local products. In addition to these already existing initiatives, however, numerous possibilities exist to advance urban agriculture. For instance, urban gardens can be created on the roofs of buildings or through the clever temporary use of fallow land and setback areas.[169] What's more, the urban development concept 'Perspektive München', a central instrument for shaping the city's future, includes securing and developing small-scale green spaces in the districts. This creates the best conditions for cooperation between citizens' initiatives and the city administration to promote urban gardening in the future.[170]

2.2 ENDORSE A BALANCED DIET

This intervention centres on food consumption: limiting caloric intake to 2,700 per day and favouring plant-based diets would serve to both **narrow** and **regenerate** material flows.

Dietary choices have a substantial impact on both human health[171, 172] and the environment.[173, 174] Research shows that the healthiest and most sustainable diet is very low in meat and high in plant-based protein and whole grains.[175, 176] In contrast, Germany's, and thus Munich's, food culture is resource-intensive and characterised by high meat consumption.[177] Overall, the average German consumption of 3,572 calories per day is well above the European (3,411 calories per day) and world (2,970 calories per day) averages,[178] and preferences in regional diets have remained relatively constant over time.[179] Munich also suffers from a high prevalence of pre-obesity and obesity, a growing health concern for the city's population. Current patterns show high food consumption with a negative impact on the environment and health. Thus, shifting to lower intake and healthier, more plant-based diets would benefit not only the environment but also people.

Sustainable food consumption is getting more support, with cities like Berlin leading the way and others following suit. Namely, the increasing importance of fair trade and organic products is gradually influencing the eating habits of individuals, while sales of organic products in Germany are now double that of the European average.[180, 181] Munich is no different; the support for organic products and a healthier diet is increasing. This is evidenced by the multiple initiatives in the region and city, such as the establishment of the food transition office, organic cooking course series from various institutions and city officials, and other similar actions.[182] To support this trend and provide the necessary incentives for consumers, factors such as product certification and traceability must be improved. Individuals are gradually demanding more transparency about the origins and cultivation methods of the products they buy. Pricing is another important consideration, as organic products often come with higher price tags, which can discourage consumers who make choices primarily based on cost without fully understanding the negative health and environmental impacts associated with their choices—or who simply cannot afford the pricier option. Thus, it is imperative to shift this perspective and educate consumers about the broader benefits of choosing more sustainable foods. Some initiatives are already in place, like the showcase of true pricing of products aiming to raise awareness and support this attitude change.[183] Overall, the share of people willing to pay for quality is increasing in most cities. It is also important to emphasise that more sustainable choices should be accessible and affordable for all consumers. As the demand for these products continues to rise, consumers are sending a crucial signal that prioritising sustainability is essential. With time, as organic farming practices become more widespread, prices will likely decrease, making more sustainable options increasingly accessible.

2.3 REDUCE AND VALORISE FOOD LOSS AND WASTE

This intervention considers strategies that can reduce avoidable food loss and valorise waste: preventing unnecessary or excess food production, for example, which **narrows** flows. All unavoidable food waste and loss should be **cycled**, following the food waste hierarchy.[184]

Germany produces a significant amount of food waste every year. In 2020, the country produced 11 million tonnes of food waste, more than half of which could be attributed to households. In Bavaria, more than 992,000 tonnes of avoidable waste are generated along the value chain every year,[185] equating to approximately 70 kilogrammes of food waste per person. Fruits and vegetables account for the largest share of wasted products at home, followed by dairy products, leftovers and pastry. However, significant losses are also associated with the wider supply chain—from primary production to processing and retail stages. Certain market policies further contribute to food loss—such as efforts to maintain market prices—leading to overproduction of certain products to compensate for low prices while inflating the prices of other products due to scarcity. Similarly, existing pressures from international trade standards, hygiene requirements, and the competitiveness between producers are contributing factors.[186] With this in mind, it is important to note that a substantial amount of waste is completely or partially avoidable and caused by several addressable factors. At home, the situation is no different. Lack of appreciation for food and poor meal planning leads to significant food waste. Inappropriate storage is also linked to a large amount of foodstuffs spoiling and being thrown away. Lastly, (mis)perceptions about 'best-before' dates commonly lead consumers to discard food that is often still edible.[187]

Germany set a target to cut food waste by 50% per capita by 2030, to mitigate losses and meet national targets for sustainable development.[188] The strategy includes compulsory measures that are constantly refined and developed, extending their reach to farms, grocery stores and other key actors within the food value chain. Munich has also set an ambitious target of halving food waste by 2030,[189] and various public initiatives are already in place to achieve this: from exhibitions and food waste prevention campaigns to the promotion of food sharing using digital apps and food donations, among others.[190]

Plenty can be done to reduce avoidable food waste. Consumers can plan their meals, store food properly and be mindful of portion sizes, ensuring that edible items are used efficiently and not unnecessarily discarded. As for unavoidable waste, the focus should shift toward better waste management. Some solutions in this realm include turning urban organic waste into high-value products through biorefineries, producing biogas and capturing nutrients to return them to the soil through industrial and community composting.[191]

IMPACTS

Scenario two's potential impact on the material and carbon footprints is laid out below in Table three.

Embracing a circular food system could also bring a range of **co-benefits** to Munich, from the improved health of its residents to lower air pollution, healthier soils in rural and peri-urban landscapes and flourishing biodiversity. Preventing food waste—in addition to helping the city meet its targets of cutting food waste in half by 2030[192]—will also benefit residents financially. After all, wasted food is wasted money. Producing food sustainably and locally could also help ensure greater resilience, protecting against future shocks—whether geopolitical, economic or health-related—while reducing import costs for import-dependent food groups, such as vegetables, fruits, nuts and others. Finally, a circular food system can also help to stimulate new business models that capitalise on circular food production and processing, circular kitchens and food waste management, creating new employment opportunities and allowing for more collaboration with local farmers to increase the quality of their soil, provide biogas for energy and decrease dependency on imported fertilisers.

INTERVENTION	MATERIAL FOOTPRINT	CARBON FOOTPRINT
2.1 Shift to more sustainable food production	-1.4%, down to 47.5 million tonnes	-1.1%, down to 34 million tonnes of CO_2e
2.2 Endorse a balanced diet	-1.8%, down to 47.3 million tonnes	-3.1%, down to 33.4 million tonnes of CO_2e
2.3 Cut food waste	-0.4%, down to 47.9 million tonnes	-0.5%, down to 34.2 million tonnes of CO_2e
Combined scenario impact	**-2.7%, down to 46.9 million tonnes**	**-3.8%, down to 33.1 million tonnes of CO_2e**

Table three shows Scenario two's potential impact.

MUNICH RESIDENTS ARE ALREADY TURNING TOWARDS PLANET-HEALTHY, LOW-WASTE FOOD OPTIONS

The diets of Munich's residents are relatively high impact as they consume a great deal of meat and calories, leading to substantial food waste. This is not optimal for the health of people or the planet. What's more, most of this food is imported, bringing with it embedded emissions that have far-reaching effects. However, by recognising the impacts of such habits, society is gradually turning towards more healthy, local and sustainable products. Such change can be notably attributed to the awareness-raising and on-the-ground work that has been carried out by several initiatives in Munich.

For instance, the Community Kitchen is a pilot project that reduces food waste through food rescue and redistribution activities. The project's vision can be summarised by the phrase 'Eat What is Already There'. Around 15,000 kilogrammes of food is donated to the Community Kitchen from producers, processors or wholesalers at the end of each day, including fresh vegetables, fruits, meat and other staple foods.[193] With these ingredients, fresh, healthy and seasonal meals are prepared and consumed in the facility or by public canteens distributing them in schools, hospitals, retirement homes and universities. To increase their impact, the Community Kitchen also focuses on providing knowledge and raising awareness about food waste and ways to avoid it to all stakeholders.

Beyond the impact on the ground, lessons learned and important insights collected by the Community Kitchen are distributed through the Good Food Cycle. This second initiative was started by Circular Munich e.V. and currently comprises more than 30 participating organisations. Aside from the Community Kitchen, several other businesses, NGOs, and public, private and academic actors have formed a network committed to implementing circularity principles in the food sector and achieving sustainability. Through collaboration, distribution of best practices and support, this network aims to drive Munich's circular food agenda.

Another important initiative: Munich's Nutrition Council. As an independent alliance of actors from civil society, politics, administration, science, business and education, the council works on fostering a sustainable, resilient and public-welfare-oriented food system in the region. The council starts at different points in the value chain and reforms them to orient the system toward seasonal, regional food from fair organic producers. Some of the focus areas are the cultivation and production methods, consumption patterns, food processing and storage techniques and the creation of edible cities which exploit their potential for urban agriculture.

3. ADVANCE CIRCULAR MANUFACTURING

Munich is a hub for manufacturing, significantly bolstering Bavaria's economy and making it one of the world's leading regions for various manufacturing activities: the sector employs almost 100,000 workers in the city alone.[194] Munich's diverse manufacturing sector ranges from automotive and mechanical engineering to chemical production, metalworking, print production and the food industry.[195] It hosts a large network of major global players in the field, from multinational companies headquartered in the capital[196] to start-ups and research institutions, playing a crucial role in driving company-related services such as consulting or research and development.[197, 198] Amidst structural transitions, manufacturing has sustained a promising revenue trend, increasing its value-added share.[199] Manufacturing is not just an economic cornerstone but also a catalyst for innovation and professional development, contributing to job creation in Munich and its surrounding towns.

We envision a circular manufacturing sector for Munich, where design optimises product lifetimes and components are reused at their highest value and in which current modes of production and sales radically change. To this end, this 'what if' scenario highlights how to:

3.1 **Advance resource-efficient manufacturing processes** and

3.2 **Employ R-strategies for machinery, equipment and vehicles.**

3.1 ADVANCE RESOURCE-EFFICIENT MANUFACTURING

This scenario's first intervention centres on improving the material efficiency of Munich's manufacturing businesses—both during the initial stages, where materials are processed and formed, and in the final stages, where products are created. By doing so, the sector would reduce the need for metal inputs, such as steel and aluminium, and therefore **narrow** flows. During the initial stages of manufacturing, gains in material efficiency and reductions in yield losses can be achieved via technological advancements. Moving further along the value chain, where metals are used to produce items like vehicles or machinery, process improvements will yield similar benefits. Additionally, optimising the management of scrap materials, which are typically by-products of standard procedures, would further enhance efficiency and reduce the need for virgin material inputs, leading to a further **narrowing** of material flows. All unavoidable scrap can also be reclaimed and reused, effectively **cycling** flows.

Munich's manufacturing and industrial hub contributes significantly to the city's high material footprint of metals and fossil fuels. Most of this footprint comes from metalworking and electrotechnical industries—Bavaria's most important industrial activities—accounting for over 2,700 companies and producing products that make up the biggest share of exports in the region.[200] Indeed, exports for motor vehicles and parts, machinery for electricity production and distribution, and measuring and control instruments are worth €214 billion for the region.[201, 202] These manufacturing processes require a great quantity of steel, most of which comes from Germany—the eighth largest steel producer in the world.[203] While German steel, in general, is transitioning from coal-powered to electric arc production processed (which represented almost 30% of production in 2022),[204] manufacturing industries are still major emitters of GHGs. Overall, **this sector is responsible for almost 30% of Munich's total carbon footprint.**

Strategies are currently being implemented in various areas to boost circularity in manufacturing value chains. Recent research and development efforts have focused on incorporating hydrogen production into steel-making processes to help decarbonise the sector.[205] To enhance resource efficiency, there is a growing trend of utilising scrap metals, effectively reducing waste generation and improving the material efficiency of manufacturing processes.[206] Scrap metal recycling is and will continue to be a pivotal practice, particularly in manufacturing activities located in Munich and Bavaria, which heavily rely on a continuous supply of metal resources. This practice not only narrows the total input of steel into the sector but also boosts efficiency in production. Industry experts are well aware of this fact, and numerous initiatives are already underway across Bavaria, Germany, and the rest of Europe to develop and implement such circular practices.[207]

3.2 EMPLOY R-STRATEGIES FOR MACHINERY, EQUIPMENT AND VEHICLES

This intervention employs various R-strategies[208] for the manufacturing of machinery, equipment and vehicles (see the text box on page 58). Remanufacturing and refurbishment practices can be leveraged in the business-to-business sector to extend product lifetimes, particularly for high-value machinery and equipment, therefore **slowing** flows. Munich's industrial manufacturing companies could also benefit from a shift to more circular supply chains, making use of leasing or other Product-as-a-Service (PaaS) systems as an alternative to ownership-based models, therefore **narrowing** flows.[209] Incorporating circularity in the early design phases at the product and system levels will also enable high-value circular practices.

Value-retention processes like remanufacturing, refurbishment, repair and direct reuse retain value and generate new local value for producers and consumers. Durable, repairable and recyclable product design (for instance, of capital equipment products) are core principles of the circular economy, and such principles should become increasingly integrated into all manufacturing processes. This transformation can be facilitated by adopting leasing models or PaaS systems. Doing so would minimise environmental impacts while developing new market opportunities and creating high-skilled jobs. Leveraging the expertise, technical knowledge and infrastructure from some of the city's largest areas of activity can quicken the transition. In fact, Germany is already Europe's leader in terms of revenue from remanufacturing activities (estimated to account for 29% of the EU's remanufacturing revenue), particularly in vehicle and engineering manufacturing sectors.[210] This shows that a major German city like Munich, given the city's and Bavaria's unique innovation,[211] can capitalise on its skilled workforce and inter-connected manufacturing sector to implement different R-strategies and advance towards a circular manufacturing sector.

A few key manufacturing companies based in Munich are already adopting R-strategies. For instance, some stakeholders are actively using parts from old vehicles,[212] including several electronic components, while pioneering the development of automated and robotised electronics remanufacturing processes.[213] These forward-thinking enterprises play a pivotal role in driving circular advancements of the sector in Munich and should receive continued support to accelerate the deployment of these new practices.

Local, regional and national policymakers will be key in making such major transformational changes across the manufacturing sector. Businesses incorporating R-strategies usually struggle to compete with conventional business models that have large output volumes of new (and cheaper) products. In this sense, circular manufacturers will need public support, for example, in incorporating the negative externalities (environmental costs) of manufacturing new products into final prices (this will likely require a shift of taxation towards the use of material resources) or through subsidies.

WHICH R-STRATEGIES DO WE CONSIDER—AND WHAT DO THEY MEAN?

- **Reuse:** The extension of a product's lifetime that therefore displaces the sale of new goods. This assumption stems from the fact that products are often still usable—even without additional repair and maintenance—but reach their end-of-use early due to consumer attitudes and behaviours.
- **Repair:** The reparation of parts of a product that limit its performance and the maintenance of parts that can help to prolong its useful life. This can happen at the inter-industry level or be performed after consumers purchase a good. Similarly, upgrades can be carried out to improve a product's functionality and extend its useful lifetime: this goes beyond repair and implies an improvement to a product, for example, by increasing mechanical-, electrical- or ICT-related inputs, depending on the product.
- **Refurbishment:** A procedure to improve the quality of a product up to a specified standard.
- **Remanufacturing:** A procedure in which all product components are completely disassembled down to their smallest parts, are fully inspected and then reused for an entirely new life cycle.

R-Strategies in the context of Munich's manufacturing sector

Munich hosts a strong manufacturing sector, whose industries typically involve the use of heavy machinery and other capital equipment, bearing high environmental impacts and economic costs. In the context of a circular transition, designing and manufacturing equipment that's built to last and be reused is essential.[214] If correctly applied by manufacturing companies, the abovementioned R-strategies have the power to harness capital equipment's circular potential by maximising value intensity and lifetime extension of machinery equipment.

Find more information about how Munich's manufacturing companies can adopt circular economy actions to optimise their use of material resources in capital equipment in this report.[215]

IMPACTS

This scenario's two interventions can reduce Munich's material and carbon footprints. See a detailed breakdown of the impacts of each intervention in Table four below.

The adoption of these interventions would also bring a range of social and economic co-benefits: increased resilience against supply chain disruptions and price volatility, triggering new business models (through circular design, PaaS and different R-strategies), and customer engagement and loyalty,[216] to name a few. Scaling the uptake of R-strategies could also induce greater private sector involvement in the circular economy and boost industrial sectors, creating new business opportunities, incentivising innovation and laying the groundwork for longer-term resilience and competitiveness. In terms of employment, this transformation also holds a high potential for new jobs, as it will require a workforce with a higher level of manual labour and specialised skills.

It is also worth noting that Munich's manufacturing and industrial base includes other important industries—such as chemicals, biotech, food and drink, and textiles,[217] for example—that are out of scope for this scenario. These highly energy-intensive sectors may also advance resource efficiency and decarbonisation via increased use of secondary materials, cutting-edge technological and industrial processes, hydrogen deployment and industrial heat recovery projects, for example.[218]

CIRCULAR INTERVENTION	MATERIAL FOOTPRINT	CARBON FOOTPRINT
3.1 Implement resource-efficient manufacturing	-1.4%, down to 47.5 million tonnes	-1.1%, down to 34 million tonnes of CO_2e
3.2 Employ R-strategies for machinery, equipment and vehicles	-11.3%, down to 42.7 million tonnes	-9.1%, down to 31.3 million tonnes of CO_2e
Combined scenario impact	**-12.2%, down to 42.3 million tonnes**	**-9.7%, down to 31.1 million tonnes of CO_2e**

Table four shows Scenario three's potential impact.

RETHINKING BUSINESS-AS-USUAL TO BOOST CIRCULAR MANUFACTURING

The manufacturing sector constitutes an important part of Munich's economic activities and has seen a positive development in terms of revenues and value added in recent years.[219] Munich's manufacturing sector encompasses a wide variety of activities, which are still far from circular. However, attention is increasingly being paid to new business models that could facilitate the sector's circular transition. These efforts take the form of both coordinated action initiated by institutions, as well as changes in the strategies and operations of individual organisations.

One important example of coordinated action is the CirculaTUM. Its goal is to shape the economy following sustainability and resilience principles, and ultimately rethink the way business is done to decouple prosperity from resource consumption. Through an interdisciplinary research network, CirculaTUM actively promotes engagement with business and society and provides a scientific contribution to industrial and societal transformation. The focus is set on innovation, nurturing systemic thinking, activating engagement and fostering entrepreneurial skills.

Another example: Encory. This company specialises in developing and operating end-to-end circular solutions for businesses. Its activities range from implementing remanufacturing projects to purchasing sustainable raw materials and achieving optimal recycling processes, through a wide range of methods like consulting, digital tools and reverse logistics. Its goal is to provide the knowledge and solutions needed to create and manage closed cycles for its clients, particularly looking at post-sale operations.

On the other hand, some businesses have successfully incorporated life-cycle circularity principles into their business models: certified carbon-neutral toothbrush brand Happybrush, for example. Happybrush focuses on sustainability, improved packaging and new solutions for its product. For instance, it minimises the absolute amount of new plastic needed for all parts of the toothbrush, equivalent to avoiding 131 tonnes of new plastic since 2019. It has also made substantial cuts in the materials used for packaging. The products are also designed to be as recyclable as possible and so that the valuable resources they contain can be reprocessed and reused. Despite its success, the company is continuing to explore new solutions and practices to improve the circularity and overall sustainability of its products.

4. PROMOTE A CIRCULAR LIFESTYLE

Overconsumption is the driving force behind the current linear economy, and it has damaging effects on environmental and human wellbeing.[220] Germany, one of the most affluent countries in the world, is characterised as a mass consumer society.[221] Consumers increasingly purchase new products, keep them for less time than they used to and buy replacements sooner.[222] Even though consumers are gradually becoming more interested in the origins and impact of the products they purchase, consumption patterns remain far from sustainable.[223] If the rest of the world consumed at the same rate as Germany, we would need three planets to satisfy the demand for materials.[224] As hotspots of consumption, cities like Munich face the primary challenge of ensuring we only consume what our planet can sustainably provide.

Munich has already started to move toward a more sustainable future, rolling out a number of initiatives regarding food waste, reducing consumption, and waste prevention and management while also being a Zero Waste Certification candidate.[225] The City's main goals are to raise citizens' awareness, reduce household waste by 15% per capita and reduce the amount of residual waste by 35% per capita. This 'what if' scenario explores the role of household consumption in a circular economy,[226] as well as the impact of such measures. We examine just one intervention linked to a 'material sufficiency' lifestyle—a low-impact lifestyle that prioritises minimalism over excess by consuming fewer resources and keeping products in use for longer.[227] In practice, this means buying and owning less, and choosing different products and services, such as Product-as-a-Service options, and practising reuse and repair. While governments and businesses must lead the way in transitioning towards a circular economy, individuals can wield their influence through their daily consumption choices, directly contributing to the reduction of environmental impacts linked to consumer goods.

4.1 EMBRACE A 'MATERIAL SUFFICIENCY' LIFESTYLE

A range of strategies can contribute to minimising material consumption, **narrowing** flows, encouraging Munich's residents to use products for longer, **slowing** flows, and using eco-alternatives and recycling as much as possible to **regenerate** and **cycle** flows. Cutting the number of consumables in circulation—**narrowing** flows—is the most impactful strategy. In order to fully embrace a 'material sufficiency' lifestyle, applying these strategies to plastics, electronics, and textiles will be key. These resource-intensive and environmentally impactful sectors are important levers, where responsible consumption can significantly contribute to circularity.

Plastics

Germany is reputed for being a plastics recycling champion: it prides itself on high plastic packaging waste collection rates, an advanced Extended Producer Responsibility scheme and a sophisticated deposit-return scheme (DRS) for bottles, for example.[228] Munich is no different, boasting an impressive municipal recycling rate.[229] Still—at least in terms of plastic packaging—Germany is far from a circular economy.[230] Germany alone generates a whopping 3 million tonnes of plastic packaging waste annually. While official statistics report that 49% of this is collected, collecting is not recycling. Incorrectly collected waste, complex plastic packaging and the downcycling of recovered materials can decrease **true recycling rates**. Furthermore, plastic is often exported for recycling, raising questions about the actual recycling outcomes in receiving countries and the spread of waste-related problems to other regions.[231] Many issues persist. Only 11% of plastic packaging is made from recycled content, and over 50% of packaging waste is used for waste-to-energy recovery through incineration.[232, 233] This translates into burning more than 1.6 million tonnes of plastic, equivalent to €3.8 billion annually.[234] Burning plastic packaging in Germany alone is responsible for 15.3 million tonnes of CO_2e emissions.[235]

Secondary or recycled plastic production is also very low compared to crude oil and natural gas production.[236] In 2019, the primary plastic production in Germany amounted to 18 million tonnes, almost one-third of total European production.[237] Over the last 25 years, the country's plastic waste has more than doubled, following increasing consumption.[238] The most important source of plastic waste comes from packaging and other single-use products, whose components are almost all virgin materials.[239] The excessive consumption of plastic is not only a concern for incineration but also a significant contributor to the pollution of natural environments. Every year in Germany, 150,000 to 266,000 tonnes of plastic end up in soils, inland waterways, the sea and the air.[240]

The current German waste management system, despite boasting low rates of mismanaged waste, still raises concerns due to the sheer amount of plastic consumption, as well as the significant reliance on waste-to-energy incineration and waste exports. Considering the magnitude of the impacts, plastic waste generation is unsustainable, and exports or recycling alone cannot solve the problem. The ultimate solution lies in consuming fewer plastics from the outset, emphasising the importance of reducing plastic usage. In Munich, residents dispose of around 42,000 tonnes of lightweight packaging (plastic packaging and composite materials such as beverage cartons) per year—equal to about 1.2 cubic metres per capita.[241] As one of Germany's major cities, Munich plays a substantial role in the overall plastic consumption problem faced by the country, emphasising the need for localised efforts to reduce plastic usage.

Textiles

Globally, the textiles industry has a significant environmental impact, characterised by extensive water and energy consumption, chemical pollution, carbon emissions, and the generation of 4% of the world's total waste, among others.[242, 243] A significant driver behind these adverse environmental impacts has been the exponential increase in textile consumption associated with fast fashion. Indeed, in recent years, German households have experienced a significant increase in the consumption of fast fashion products, driven by the cheaper, short-lived seasonal consumption cycles that such brands propose. In fact, fast fashion has rapidly emerged as one of the largest sectors within the German consumer goods manufacturing industry.[244] This comes at the expense of local textile industries, primarily made up of medium-sized companies, who have seen their turnover weakened by the short cycles and the competitive advantage (lower prices) of these new fast-paced multinationals.[245]

In Munich, the textile problem is not unique but more pronounced due to the high average income of its residents. Yet while the consumption of new items prevails, clothing reuse and second-hand shopping are becoming increasingly common. Recycling centres and clothing containers play a pivotal role in collecting old textiles, with a total of 5,000 tonnes of household-generated textile waste collected in 2020.[246] Old textiles are collected at recycling centres and clothing containers and then prepared for reuse and resale. A nationwide label is then applied to distinguish upcycled clothing and incentivise individuals to use second-hand items. This label has increasingly been seen as trendy and gaining popularity among consumers.[247] However, the increasing collection rate of textile waste went hand in hand with a decline in the quality of collected goods due to the increasing number of fast fashion suppliers. As a consequence, recycling costs have risen, and a significant portion of collected waste must be disposed of during sorting, amounting to nearly 52,000 tonnes, or 4% of the total textile waste collected.[248] Other initiatives in Munich include awareness campaigns and events showcasing sustainable clothing, alongside certifications indicating eco-friendly production methods in an increasing number of shops.[249, 250]

Despite demand shifting away from fast fashion, Munich faces persistent barriers. A strong preference for lower-priced products remains challenging, inhibiting residents from making more sustainable choices. Moreover, there's a need to bridge the gap between greater consumer awareness and actual behavioural changes, emphasising the importance of addressing cultural attitudes and pricing as enablers for a more circular textiles value chain.[251]

Electronics

Germany, as the largest electronics and electrical market in Europe and the fifth-largest globally, has witnessed a significant surge in electronic waste generation over the past decade.[252, 253] Over the last ten years, an average of 880,000 tonnes of electrical and electronic equipment waste has been produced in the country annually—approximately 12.5 kilogrammes per capita in 2020 (compared to 9.31 in 2018).[254, 255] Bavaria, in particular, hosts a very advanced electronics sector, with Munich serving as the home base for numerous prominent electronics companies spanning various facets of electrical engineering and electronics.[256, 257] Electronics production, primarily centred around automotive and industrial electronics, continues to escalate each year, with a remarkable 60% increase observed in 2019 compared to 2013. This increase reflects the expanding applications of electronics, diminishing product lifespans, and an uptick in consumption, leading to a proportional rise in waste generation.[258] Munich alone collects a staggering 8,000 tonnes of electronic scrap every year.[259]

To deal with the increasing amount of waste, Germany has implemented a mechanism known as 'divided product responsibility'.[260] Under this legal framework, primary obligations for electrical and electronic waste disposal are borne by public sector recycling entities and electrical and electronic device manufacturers. Ambitious recycling targets have also been set to drive progress. However, as of 2019, the recycling target (65% of the average weight of electrical and electronic devices placed on the market in the previous three years) fell short, with a collection rate of just 44%.[261]

It is evident that recycling alone cannot fully resolve the e-waste issue, particularly in the face of increasing consumption. A significant portion of the German population remains unaware of the far-reaching impacts of extensive e-waste.[262] Different strategies and actions must be supported, like repair, refurbishment, and responsible consumption and production. Specifically, the repair and reuse principle is important to effectively reduce e-waste and cultivate different consumption habits.[263] In this context, Bavaria has initiated a scheme rewarding residents with grants for repairing their devices rather than discarding them.[264] Additionally, Munich is now home to various facilities like Repair Cafes, where residents can either repair their electronics or learn how to do so.[265] Nevertheless, the prevalent consumer tendency in the country leans towards replacement rather than repair.[266] SOffering economic incentives for consumers will help scale up repair practices.[267] Furthermore, producers need to factor in the end-of-life process of their products during the design phase and prioritise the avoidance of harmful substances to minimise adverse environmental effects.[268]

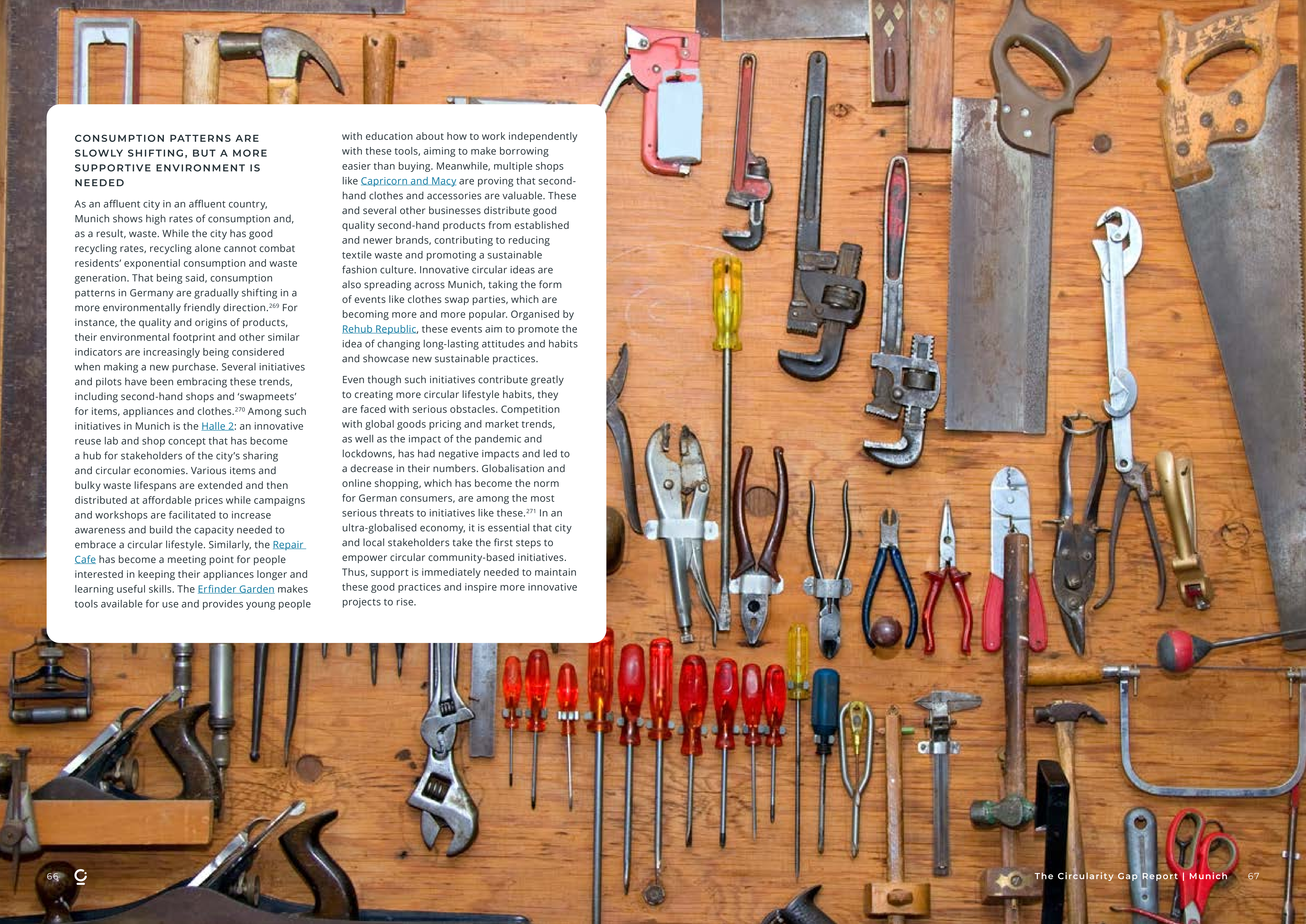
IMPACTS

This scenario's single intervention can have a substantial impact on Munich's material and carbon footprints. See a detailed breakdown in Table five below.

This scenario could also bring a range of co-benefits. First, it promises a reduction in waste, litter and pollution, aligning with Munich's aspirations to become a Zero Waste Certified City. Secondly, by promoting sustainable, community-centred lifestyles, Munich can enhance inclusivity and resilience within its society. The shift towards reduced consumption addresses the pressing cost of living crisis, channelling consumers towards products that enhance their overall quality of life and well-being, ultimately leading to cost savings. Lastly, this scenario can support local businesses and industries by increasing consumers toward local products. Businesses specialising in restoring goods and managing waste will have room to flourish and develop, creating new jobs and opportunities for the city.

INTERVENTION	MATERIAL FOOTPRINT	CARBON FOOTPRINT
5.1 Embrace a 'material sufficiency' lifestyle	-10.2%, down to 43.2 million tonnes	-13.9%, down to 29.6 million tonnes of CO_2e

Table five shows Scenario four's potential impact.



CONSUMPTION PATTERNS ARE SLOWLY SHIFTING, BUT A MORE SUPPORTIVE ENVIRONMENT IS NEEDED

As an affluent city in an affluent country, Munich shows high rates of consumption and, as a result, waste. While the city has good recycling rates, recycling alone cannot combat residents' exponential consumption and waste generation. That being said, consumption patterns in Germany are gradually shifting in a more environmentally friendly direction.[269] For instance, the quality and origins of products, their environmental footprint and other similar indicators are increasingly being considered when making a new purchase. Several initiatives and pilots have been embracing these trends, including second-hand shops and 'swapmeets' for items, appliances and clothes.[270] Among such initiatives in Munich is the Halle 2: an innovative reuse lab and shop concept that has become a hub for stakeholders of the city's sharing and circular economies. Various items and bulky waste lifespans are extended and then distributed at affordable prices while campaigns and workshops are facilitated to increase awareness and build the capacity needed to embrace a circular lifestyle. Similarly, the Repair Cafe has become a meeting point for people interested in keeping their appliances longer and learning useful skills. The Erfinder Garden makes tools available for use and provides young people with education about how to work independently with these tools, aiming to make borrowing easier than buying. Meanwhile, multiple shops like Capricorn and Macy are proving that second-hand clothes and accessories are valuable. These and several other businesses distribute good quality second-hand products from established and newer brands, contributing to reducing textile waste and promoting a sustainable fashion culture. Innovative circular ideas are also spreading across Munich, taking the form of events like clothes swap parties, which are becoming more and more popular. Organised by Rehub Republic, these events aim to promote the idea of changing long-lasting attitudes and habits and showcase new sustainable practices.

Even though such initiatives contribute greatly to creating more circular lifestyle habits, they are faced with serious obstacles. Competition with global goods pricing and market trends, as well as the impact of the pandemic and lockdowns, has had negative impacts and led to a decrease in their numbers. Globalisation and online shopping, which has become the norm for German consumers, are among the most serious threats to initiatives like these.[271] In an ultra-globalised economy, it is essential that city and local stakeholders take the first steps to empower circular community-based initiatives. Thus, support is immediately needed to maintain these good practices and inspire more innovative projects to rise.

5. REDESIGN MOBILITY

Getting people and products from one place to another is highly carbon- and material-intensive in modern societies. We depend heavily on private cars for everyday commuting, and trucks, trains, ships and aeroplanes for longer-distance travel and freight shipping. In Bavaria—and Germany more broadly—mobility is still largely dependent on fossil fuels and is a significant contributor to GHG emissions (responsible for 45% and 20% of direct emissions, respectively). Recent trends show that overall transport emissions are increasing year on year.[272, 273] Road traffic is responsible for the largest share of those emissions (up to 95%), negatively impacting the environment and residents due to air and noise pollution.[274] This has recently given rise to heated debates about a deep transformation of the mobility system. The region's proposed measures for climate transformation reveal that enormous CO_2 savings could be achieved, especially in the transport sector. Aviation is another important (and growing) cause for negative externalities, both at a global scale[275] and in Germany.[276, 277]

Munich's airport is one of the busiest in Europe, with growing traffic and environmental impacts. Unfortunately, decarbonisation plans have so far proven insufficient, as they fail to address emissions from the flights themselves (which represent 76% of the city's total aviation emissions).[278] Overall, the mobility sector needs to undergo a serious transformation to meet national and European targets. Already, several measures have been considered and rolled out.

This 'what if' scenario provides a reimagination of transport and mobility in Munich by modelling two interventions:

5.1 **Reduce or avoid unneccesary travel** and

5.2 **Drive cleaner urban mobility forward.**

Ensuring the optimisation and decarbonisation of all transport across Munich—from cars and trains to aeroplanes—will require broader and more systemic change.

5.1 REDUCE OR AVOID UNNECESSARY TRAVEL

This scenario's first intervention explores the benefits of decreasing or avoiding travel or the need for travel by rethinking the mobility system. This will ultimately require Munich's residents to embrace a car-free lifestyle, reduce air travel and continue to allow workers to work from home where possible. Doing so could cut the need for private car use and fuel consumption, both serving to **narrow** flows. However, it's worth noting that increased public transport (train and bus) coinciding with and causing a significant reduction in private car ownership and use will offset the expected decrease in material use to a degree.

Reduce air travel

Munich is the second busiest airport in Germany, following Frankfurt, and the 6th busiest in Europe.[279, 280] In spite of a slow-down due to the covid-19 pandemic,[281, 282] air traffic has returned to pre-pandemic numbers and is increasing year after year.[283, 284] While multiple efforts are in place to mitigate the airport's environmental footprint and achieve carbon neutrality ambitions by 2030—such as the installation of air curtains in terminals, renewable energy installation and carbon compensation)[285]—environmental pressures are still considerable. In fact, GHG emissions from air traffic at Munich's airport (Scope 3) are responsible for the largest share of the airport's emissions: the airport currently has little influence over this, as the number of flights is determined by factors such as customer demand and airline- or country-level policies.[286] Aside from GHG emissions, the airport is also working towards increasing and protecting biodiversity, efficient waste management, and reducing resource consumption.[287] However, these measures fail to reduce the need for air travel in the first place. Moreover, domestic flights constitute a big part of Munich's air traffic,[288] which should and could be vastly reduced. Promoting alternative modes of transport—especially for shorter distances—could slow the growing air travel rates. For instance, as recently announced by the German federal government, €12.5 billion of the newly created Climate Fund will be going to renovate and expand the Deutsche Bahn railway network, helping address this issue.[289]

Pursue a modal shift for transport

Private cars generally play a central role in mobility in Germany.[290] In Munich, this is less the case: it boasts a well-developed public transport network and lower-than-average car density (roughly 400 per 1,000 inhabitants) than Bavaria, Germany and the EU.[291, 292, 293] Nevertheless, private cars remain an important feature of Munich's mobility—851,000 motor vehicles were registered in the city in 2020, 85% of which were passenger cars, and with an increasing number of SUVs on the roads (the share of SUVs in Munich almost doubled between 2016 and 2020).[294] High numbers of larger cars[295] and high mileages are significant causes of rising traffic and pollution. Besides impacts on residents' health and natural ecosystems, time loss due to congestion is also an important issue—Munich is by far the most congested city in the country, with the average driver losing 65 hours in traffic jams in 2020.[296] Still, new passenger car registrations are increasing year on year. To help reduce the number of private vehicles on the road, reduce congestion and lower fuel consumption, a full-scale modal shift is required in Munich's mobility system.

Pre-pandemic urban mobility in Munich was relatively balanced between different modes of transport: 25% of trips were made by public transport, 23% by private car, 9% by car with another driver, 18% by bicycle and 25% by walking.[297] However, the pandemic has led to a decline in the use of public transport in favour of private transportation modes.[298] Despite this recent shift, Munich boasts the second-highest share of trips made with alternative options in Germany.[299] Munich offers a diverse set of public transportation options to its residents: the city is covered by tram, bus, underground and metro lines, which are complemented by a vast cycling network, allowing millions of passengers to move around the city every year.[300, 301] These options help reduce overall kilometres travelled by car and, therefore, direct tailpipe emissions, which is why they should continue to be promoted and supported. Additionally, several options for shared mobility are already operating within the city. For instance, city bike-sharing services were introduced in 2015, with over 4,500 bikes now available for rent around the city.[302] The shared mobility market has steadily made its way towards German cities in the last few years,[303] and in Munich, Mobility-as-a-Service options are already supported by a number of companies.[304] However, people adopting such methods of transportation belong to a certain socio-demographic group, and their choice heavily depends on their daily needs and habits.[305] To ensure broader inclusion in shared mobility solutions, Munich should focus on tailored marketing strategies and accessibility improvements that address the unique needs and preferences of diverse demographic groups, ultimately making these options more accessible and appealing to a wider range of residents.

Hybrid or flex work: work from home

Remote work became widespread in Germany during the covid-19 pandemic.[306] Since then, Germans work remotely an average of 1.4 days per week,[307] and employees seem to have a growing satisfaction and interest in the possibility of working from home at least part-time.[308] Of course, this can only be a viable option for certain industries, and this varies across regions.[309] For instance, service providers, and in certain contexts, certain activities in the manufacturing sector, are likely to have more people working remotely,[310] which implies that this 'new normal' would particularly fit Munich's workforce, given the share of workers employed in those industries.[311]

Remote work has multiple effects on the environment. As the need to commute to and from work declines with remote work, traffic, energy use (fuels) and pollution[312] are reduced. In Germany, working remotely twice a week could help avoid 36 billion passenger kilometres travelled, cutting commuting GHG emissions by up to 18%.[313] This would also have social advantages, as individuals could spend the time once dedicated to commuting to work to fulfil their personal needs and interests instead. This kind of work also supports the development of rural areas along with urban ones, as residents are more readily able to move away from big cities while maintaining their professional activities.[314] However, there are potential trade-offs: for example, more time spent at home for work could lead people to travel more often for leisure or looking for larger houses (see Scenario one on page 42). Policymakers, employers, and individuals alike should work collaboratively to strike a balance that maximises the benefits of remote work while minimising any unintended negative consequences on the environment and society as a whole. This approach will require that many factors be considered, from work efficiency to implications for urban planning, transportation and housing trends.

5.1 DRIVE CLEANER URBAN MOBILITY FORWARD

While the main focus should be on rethinking Munich's mobility system, and reducing or avoiding unnecessary car and air travel, clean new technologies are also needed. This intervention comprises several strategies that tackle the vehicles' production and use phase. Munich can **narrow** material flows by prioritising small(er), more lightweight, fuel-efficient vehicles, thereby cutting material and fuel use for private cars, public transport vehicles and freight transport. Moving towards the future, all new public and private transport vehicles should also be electric: this would cut fossil fuel use and **narrow** and **regenerate** flows if the vehicles were powered by renewable energy. It is worth mentioning that entirely electrifying the current mobility system is not a desirable solution either, as it would come with great challenges such as the rising demand for critical materials or concerns about accessibility and equity issues due to generally higher costs.[315] This is why this intervention must be understood in the context of the previous one—i.e., complementing a substantial reduction in the fleet size and shift in modal split—to mitigate negative trade-offs and knock-on effects.

Electric, lightweight mobility

The German market for electric vehicles is growing fast,[316] and Germany is rapidly positioning itself as the lead provider and largest market for e-mobility solutions: the federal government aims to have 15 million fully electric vehicles on the roads by 2030, for example.[317] In 2023, roughly 25,000 electric passenger cars were registered in the Munich Metropolitan Region, more than in any other major city in the country.[318] However, recent trends suggest that despite the gradual electrification of private vehicles, the share of compact and small cars in Munich is actually losing ground compared to the new registrations of larger cars, such as SUVs and off-road vehicles (4x4s).[319, 320] While most policies currently focus on favouring the uptake of electric or hybrid vehicles to minimise CO_2 emissions (regardless of vehicle weight),[321] additional measures such as higher taxation based on the actual weight of cars (usually larger and or more material-intensive ones) could help to move towards a more lightweight private vehicle fleet.

However, as mentioned in the previous section, private vehicle ownership (even of electric and lightweight vehicles) should not be the top priority. Lightweight and clean urban mobility are advancing in public transport and alternative mobility options and should be further explored. Munich's automotive and mobility companies are using divergent innovative and R&D strategies to meet the challenges of a sector undergoing a major transformation toward electrification, digitalisation and better-connected mobility services.[322] For instance, Munich's trams and metro lines already run on 85% climate-neutral electricity, and the bus fleet is expected to be fully electrified by 2035.[323] Munich also supports electric micro-mobility within the city through various forms—electric bikes and scooters are becoming more and more accessible, and the city even has its own funding programme for organisations and individuals providing climate-neutral mobility solutions and infrastructure.[324, 325] If correctly deployed, such options can help achieve net emission reductions compared to conventional modes of transport.[326]

However, cities should also be mindful of social considerations behind micro-mobility—high costs, physical ability and technical skills could exclude certain social groups from using such modes.[327] Furthermore, micro-mobility options are not a magic solution to urban mobility. They are most successful when coupled with the right policy instruments, such as pricing and regulations on car travel, partnering with public transport agencies, but also the development of infrastructure, such as protected and well-connected bike lanes, that optimise the safety and travel time of such options.[328]

IMPACTS

The impact of this final scenario's two interventions can be seen in Table six below.

Munich could also experience a range of environmental, societal and economic **co-benefits** from embracing these strategies: improved air quality, less noise, and more and safer room for amenities and green spaces, for example. Improving interregional and intercity connectivity can provide economic benefits by boosting regional productivity and encouraging multiple economic centres. Taking these steps can also have multiple co-benefits for health and well-being: more active mobility would boost physical activity, potentially reducing obesity, for example.[329] A flexible, hybrid mix of work-from-home and office time could also positively influence productivity, health and well-being and bring social benefits. However, potential downsides, such as adverse economic impacts for local and regional economies, diminished collaboration and social interaction, and fair distribution of extra costs by employers and employees, should also be considered and addressed.

CIRCULAR INTERVENTION	MATERIAL FOOTPRINT	CARBON FOOTPRINT
5.1 Reduce or avoid travel, or the need to travel	-3.2%, down to 46.6 million tonnes	-4.3%, down to 32.9 million tonnes of CO_2e
5.2 Drive cleaner mobility forward	-0.7%, down to 47.8 million tonnes	+1.4% up to 33.9 million tonnes of CO_2e*
Combined scenario impact	**-3.7%, down to 46.4 million tonnes**	**-4.4%, down to 32.9 million tonnes of CO_2e**

Table six shows Scenario five's potential impact.

** The carbon footprint would increase slightly from lightweighting offset by a potential increase from electrification. The reason for this is two-fold: supply chain emissions from renewable energy sources are much higher than for fossil fuel ones, and limitations in the modelling approach to better estimate emissions reductions during the use phase—while the real benefit of electrification lies in the reduction of tailpipe (household) emissions. Therefore, it's expected that the impact of this intervention on the carbon footprint could be far greater than it appears.*

RESHAPING URBAN MOBILITY PATTERNS WITH SMART AND SHARED MOBILITY SOLUTIONS

As in the rest of Germany, Munich is home to many private cars and is suffering from increasingly bad traffic—despite walking, public transport and cycling also being common. Achieving an even greener mobility system will be fundamental to improving Munich residents' quality of life and reaching sustainability goals.

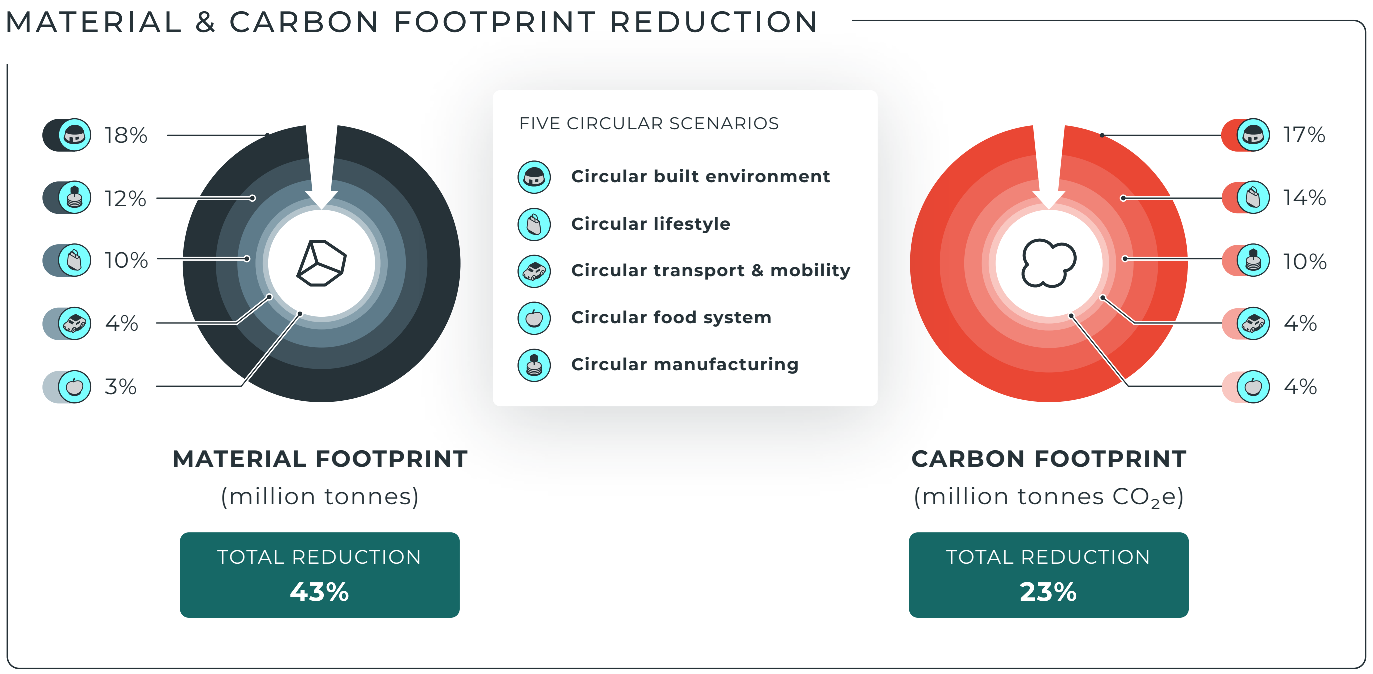
The City recognises this and is already rolling out initiatives to make car-free living easy and accessible. Shared mobility options—from shared bikes and e-scooters to cars—are now available around the city, while plans to optimise and expand the shared mobility network are already underway. This will make it more efficient and convenient by, for example, accounting for each district's density. Testing new ideas and practices—through pilot projects, among other initiatives—is also important for the city.[330] The Bergbus, for example, allows individuals to visit the mountains through routes that were previously only accessible by car. Improving the public's perception of shared mobility will be a crucial next step to ensure Munich's residents make the most of these new opportunities.

Another important initiative helping Munich achieve its goals is the Digital Hub Mobility: This platform brings together technology and large companies, SMEs and start-ups from the mobility industry to exchange ideas and shape the mobility of the future. It belongs to the broader Digital Hub Initiative and uses the environment of UnternehmerTUM to create digital mobility innovations centred on sustainability.

COMBINED INTERVENTIONS

While individual interventions have a limited impact on the material and carbon footprints, benefits multiply when interventions are combined. Because material consumption and GHG emissions are strong proxies for environmental impact, reducing them is a primary means of reducing environmental pressures. To this end, increasing materials circularity in a socioeconomic system—replacing virgin with secondary materials—is just one way of reducing the overall material and carbon footprint (and thus environmental impacts). However, constraining the overall demand for materials has a much more significant effect on lowering the material and carbon footprints with fewer interventions needed. In this sense, the scenario analysis is very useful for exemplifying the limits to cycling relative to (material) consumption reduction.

In our broad 'what-if' image for the economy, if we harness the cross-intervention synergies, **Munich's material footprint could be lowered by a remarkable 43%, from 47 to 28 million tonnes.** On a per capita basis, the material footprint could be reduced from 33 tonnes to around 19 tonnes per year, an important first step in bringing the figure close(r) to what is suggested to be a sustainable level (8 tonnes per person per year[331]). The combined scenarios also offer deep emissions reductions: **the carbon footprint could decrease by 23%, bringing it from 34 million tonnes of CO_2e down to 26 million tonnes of CO_2e.**



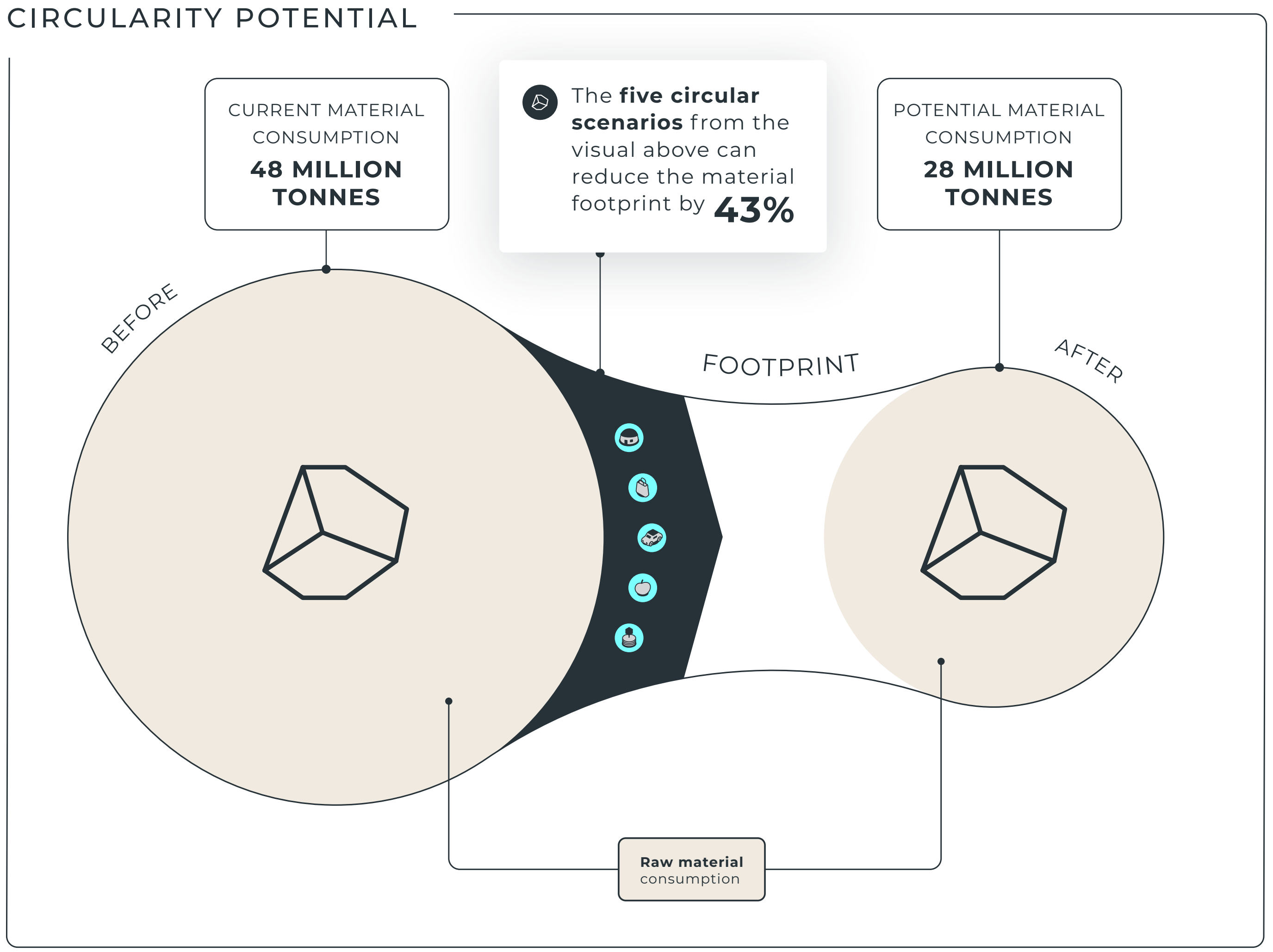


Figure five shows a summary of the material and carbon reductions made possible by applying the five circular scenarios.

SCENARIO ONE

BUILD A CIRCULAR BUILT ENVIRONMENT

1.1 Optimise building stock expansion & increase occupancy rates

- Decrease virgin material use for residential construction
- Cycle construction and demolition waste
- Enforce incentives for cohousing and multifunctional spaces
- Increase occupancy by taxing unoccupied spaces

1.2 Shape a low-carbon, energy-efficient building stock

- Carry out deep retrofits
- Make use of smart metres

1.3 Shift to resource-efficient building practices

- Choose lightweight building materials
- Prioritise modular and off-site construction
- Increase the lifetime of bearing elements
- Keep supply chains as local as possible

IMPACT SCENARIO ONE

- Reduction of material footprint by **18%**, decrease from 48 to **39 million tonnes.**
- Reduction of carbon footprint by **17%**, decrease from 34 to **29 million tonnes** of CO_2e.

SCENARIO TWO

SHIFT TO A CIRCULAR FOOD SYSTEM

2.1 Shift to more sustainable food production

- Shift to organic, local and seasonal food production
- Reduce animal production and associated products
- Reduce the need for synthetic fertilisers
- Support and promote urban agriculture

2.2 Endorse a balanced diet

- Limit the caloric intake per day and favour plant-based diets
- Support of organic products
- Provide incentives for consumer and increase awareness
- Increase transparency about the products' origins

2.3 Reduce and valorise food loss and waste

- Prevent unnecessary or excess food production
- Reduce avoidable household waste
- Raise awareness about correct planning of meals, better consumption patterns and appropriate storage
- Support initiatives like food sharing and food donations

IMPACT SCENARIO TWO

- Reduction of material footprint by **2.7%**, decrease from 48 to **47 million tonnes.**
- Reduction of carbon footprint by **3.8%**, decrease from 34 to **33 million tonnes** of CO_2e.

SCENARIO THREE

ADVANCE CIRCULAR MANUFACTURING

3.1 Implement resource-efficient manufacturing

- Improve industrial processes to reduce virgin inputs for key manufacturing industries
- Reduce yield losses
- Divert scraps and cycle unavoidable waste

3.2 Employ R-strategies for machinery, equipment and vehicles

- Increase the lifetime of machinery, equipment, and vehicles through R-Strategies such as reuse, repair, refurbishment and remanufacturing.

IMPACT SCENARIO THREE

- Reduction of material footprint by **12%**, decrease from 48 to **42 million tonnes**.
- Reduction of carbon footprint by **9.7%**, decrease from 34 to **31 million tonnes** of CO_2e.

SCENARIO FOUR

PROMOTE A CIRCULAR LIFESTYLE

4.1 Embrace a 'material sufficiency' lifestyle

- Minimise consumption of electronics, appliances, furniture and textiles
- Encourage product repairs
- Boost non-market and community service

IMPACT SCENARIO FOUR

- Reduction of material footprint by **10%**, decrease from 48 to **43 million tonnes**.
- Reduction of carbon footprint by **14%**, decrease from 34 to **27 million tonnes** of CO_2e.

SCENARIO FIVE

RETHINK TRANSPORT & MOBILITY

5.1 Reduce or avoid travel, or the need to travel

- Reduce the need for private car ownership and use
- Reduce the need for air travel
- Continue to work from home where possible to lower commuting needs and thus demand on transport
- Increase the number of journeys taken by public transport

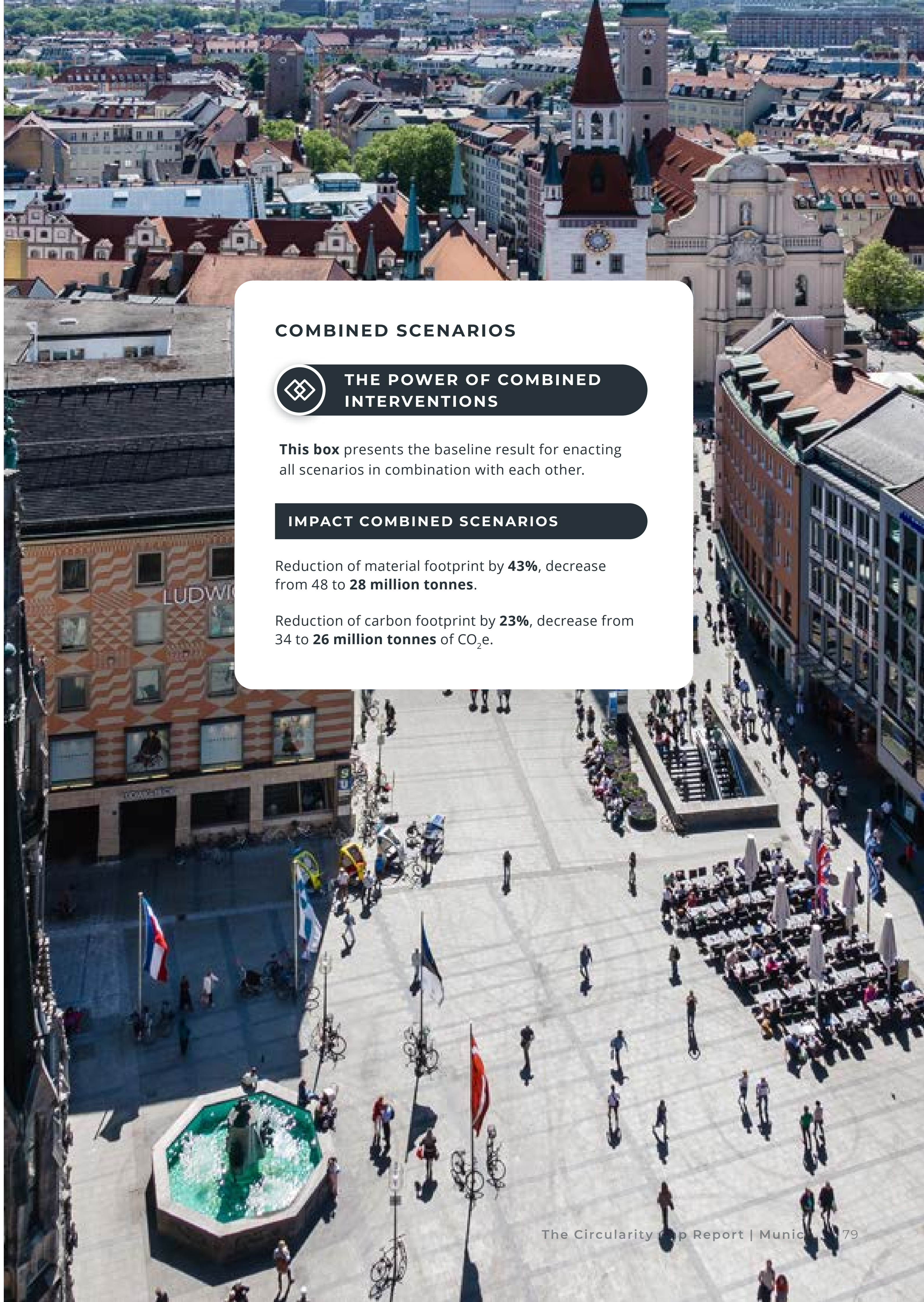
5.2 Drive cleaner urban mobility forward

- Electrify the bus and car fleet
- Power electricity through renewable sources
- Use lightweight vehicles to reduce metal input and increase fuel efficiency

IMPACT SCENARIO THREE

Reduction of material footprint by **3.7%**, decrease from 48 to **46 million tonnes**.

Reduction of carbon footprint by **4.4%**, decrease from 34 to **33 million tonnes** of CO_2e.



COMBINED SCENARIOS

THE POWER OF COMBINED INTERVENTIONS

This box presents the baseline result for enacting all scenarios in combination with each other.

IMPACT COMBINED SCENARIOS

Reduction of material footprint by **43%**, decrease from 48 to **28 million tonnes**.

Reduction of carbon footprint by **23%**, decrease from 34 to **26 million tonnes** of CO_2e.

5 THE WAY FORWARD

By implementing circular economy strategies across five key sectors, Munich can start transforming its economy and reduce environmental impacts within and beyond its borders. Satisfying the material demand of Munich's businesses and citizens takes large quantities of resources, most of which come from outside the city's borders, from the rest of Germany and beyond. This drives environmental impacts—from pollution, resource depletion, biodiversity loss and water stress to many others—worldwide. The city needs a systemic transformation that enhances ecological, social and economic resilience while meeting societal needs. **This report illustrates how circular economy strategies can be leveraged for Munich's transformation into a sustainable and thriving city.** It outlines five scenarios that could drive the city's circular transition by swapping out material- and emissions-intensive linear processes for ones that make the most of materials' value, minimise waste and help regenerate natural systems. **Overall, the strategies presented in this report can cut Munich's material and carbon footprints by 43% and 23%**, respectively.

While a few key areas hold the greatest potential for impact reduction, transformative change is needed across the board—for which a systemic approach will be needed to mobilise resources and catalyse positive change. Of the scenarios explored, **Building a circular built environment** offers the greatest opportunity for material and carbon footprint reductions, especially through strategies such as optimising future expansion of the building stock, promoting the adaptive reuse of existing spaces, and prioritising recycled construction materials for new constructions. The impact can also be substantially reduced through strategies for **manufactured goods**, both from the production side—with a greater engagement from manufacturing companies in offering various remanufacturing and repair services—and on the consumer side—by shifting towards a material-sufficiency lifestyle. Shifts in such sectors will require strong, direct support from the city regarding urban infrastructure transformations and sending the right market signals. However, consumers will also have a role in the circular transition: awareness-raising and education efforts will be needed to encourage Munich's residents to embrace a circular lifestyle, prioritise efficient energy use in their households and adopt a balanced diet, for example. Regardless of the key actor or strategy type, all strategies must be pursued with similar commitment and viewed holistically. Benefits to other environmental parameters and socioeconomic factors should be considered in addition to material and carbon footprint reductions.

The analysis presented in this report will provide a strong evidence base to inform the City's long-term circular economy strategy. The city's circular economy strategy will pave the way for action on-the-ground, but will require a shared vision, well-informed, coherent policies and instruments and substantial funding to realise. A crucial first step: prioritising key intervention areas through an evidence-based approach. The City may then form action plans for each intervention area, assigning roles and responsibilities to various stakeholders. The journey from a linear to a circular economy will be a multi-faceted endeavour requiring alignment and collaboration between policymakers, businesses and citizens—the City can nurture and encourage these relationships.

Continually measuring progress along a range of circularity indicators will be crucial to achieving targets. The City should aim to update its Circular Indicator Set regularly and expand its scope to include other process and impact indicators. Research and practical experience underscore the indispensable role of a systematic data-driven approach to circularity. By quantifying key material flows and their associated impacts, this report provides Munich with a comprehensive 'report card' for circularity, which can inform decision-making. Public and private actors may also set their own ambitious targets for circularity. They may employ other measurement frameworks to track circular strategies such as repair or reuse—both of which remain typically difficult to measure. To do so, expanding data availability through statistical databases and surveys and aligning with a broader European measurement framework for urban circularity will be crucial.[332] This endeavour must also acknowledge how Munich's circular economy goals are connected to broader sustainability objectives, emphasising the wide-ranging economic, social, and environmental benefits that effective circular actions can bring.

A significant opportunity for Munich—and the risk of missing out. Although the city exhibits very high levels of material consumption, it is well-positioned to take on the challenge of going circular to transform its economy and drastically reduce its environmental impact worldwide. With well-formed resource management and decarbonisation goals and the circular economy increasingly accepted as a means for achieving long-term sustainability aims, Munich has already taken its first steps to leave the linear model behind. Proactive stakeholder engagement will be key to the transition's success—and with plenty of collaboration programmes and bottom-up initiatives already in place between business and academia that span sectors, the Bavarian capital has all the ingredients needed for circularity to succeed and to become a world-leading circular innovation hub.

The circular economy transition can tackle multiple objectives that will bring Munich many benefits: mitigating climate and ecological breakdown, improving human wellbeing, fostering continued research and development in local educational institutions, and shaping a more dynamic, productive, resilient and innovative economy. Through close collaboration and systemic changes that permeate the local government, the private sector and individuals, 'going circular' can become Munich's new reality.

Munich's municipal government will have a crucial role in the transition: it must adopt an innovative and comprehensive governance approach to guide the circular transition. Working in silos is counterproductive to a systemic transformation: it results in fragmented efforts, inefficient resource use and missed opportunities. This can substantially limit the potential positive impacts of circular economy measures.[333] Proactive engagement from members of local authorities, businesses, academia and civil society will be needed to pave the way for open dialogue, exchange information and best practices, identify common challenges and co-create viable solutions. The City will be integral in guiding this process. Recommendations for the City are presented on pages 84–85. While the municipal government will be central in driving circularity forward, all stakeholders must be involved to ensure a systemic transition. Key actions for other stakeholders are presented on pages 86–87.

RECOMMENDATIONS FOR THE CITY OF MUNICH

MOBILISE ALL STAKEHOLDERS THROUGH A COMPREHENSIVE AND HOLISTIC CIRCULAR CITY STRATEGY:

This report provides crucial insights that will inform the design and implementation of Munich's circular strategy, which is currently at its inception. The first task will be to define the shared vision, goals, milestones and actions that will guide the implementation of the strategy in the long term. This will set the direction and build momentum towards long-term change while determining how this direction is governed. Developing and implementing the Strategy will require public consultation and coalition-building.

BRING LOCAL COMMUNITIES AND BUSINESSES ON BOARD THROUGH EDUCATION AND AWARENESS RAISING:

A systemic transition to a circular Munich will entail increasing awareness and building necessary skills and knowledge around circular practices. Munich may garner inspiration from cities that have launched living labs (using idle public buildings, for example) to foster engagement with local communities, creating an environment that promotes knowledge exchange and learning.[334] The City could also leverage the knowledge of local experts and the expertise of important industries to drive change across the business ecosystem.

MANAGE THE URBAN LANDSCAPE TO CREATE AN ENABLING ENVIRONMENT:

Some of this report's interventions will require a substantial transformation of urban infrastructure, such as the deep renovation of the building stock or a modal shift in urban mobility. Munich's local government can do this through measures such as spatial planning (for example, planning for 15-minute neighbourhoods), procurement, asset management (for instance, finding new uses for idle spaces and buildings), and the development and improvement of public infrastructure (such as cycling lanes and green roofs).

SUPPORT AND INCENTIVISE NEW BUSINESS MODELS AND OPPORTUNITIES:

Munich's strong business ecosystem represents a unique force to drive circular action and can lead essential activities of this transition in collaboration with the city. For key sectors of the economy, large companies can play an important role in reducing the material and carbon footprints of their manufacturing processes and value chains, and must therefore be supported by the City. Similarly, local authorities can use subsidies, grants, guarantees and technical advice to support small- and medium-sized enterprises (SMEs) in adopting circular models and practices. This can help them overcome typical limitations stemming from, for example, limited internal capacity and resources to launch new circular products or services, and mitigate investment risks. This is essential to leverage the potential of existing initiatives that have already built momentum on the ground, deploying the circular economy on all fronts.

REGULATE AND ENFORCE LEGISLATION:

The City can formally use its legal authority to impose obligations on itself, the local market, and consumers to boost circularity, through product standards or the banning of certain products or practices, for example.

KEY ACTIONS FOR OTHER STAKEHOLDERS

Early local adopters can serve as role models, showcasing the benefits of circular practices and the potential to drive innovation (for example, CIRCULAR REPUBLIC), offer new services and products (for example, the Repair Café, Happybrush or the Erfinder Garden), create new markets (for example, second-hand shops like Capricorn and Macy), and engage with the local community to raise awareness (for example, the second-hand department store Halle 2, and the Community Kitchen). Pioneering businesses and initiatives are also well-positioned to provide policymakers and other businesses with valuable insights into the practical challenges they have faced along their journeys.

Businesses and industry representatives, particularly from Munich's key sectors such as motor vehicle manufacturing, machinery and equipment, electronics, and technological industries (for example, BMW, MTU Aero Engines, Siemens, Infineon Technologies) and others, **can drive change across all industries and can even have far-reaching influence from a business perspective.** They can do so by adopting sustainable and regenerative practices (in material or energy sourcing, for example), engaging with supply chain partners to optimise processes and ensure transparency, embracing lightweight and circular design and production processes, and ensuring that products are designed to last for as long as possible and are easy to recycle or reuse.

Industry experts, knowledge partners and members of academia can complement the City's efforts to improve awareness, provide technical knowledge and inform public and private stakeholders. This project acts as a first example: roundtable discussions were held to identify circular opportunities and barriers for Munich through various stakeholders' expertise. It engaged a range of local industry experts and representatives (Utility companies, Chamber of Commerce), members of academia (from the Technical University of Munich, the University of Applied Sciences and Ludwig Maximilian University), and technical experts (such as Circular Republic and Prognos). Deeper, continuous engagement from these stakeholders will be essential to guide the implementation of Munich's circular economy strategy.

Local organisations can ensure that public and community interests are represented. Organisations like Circular Munich or Rehab Republic must ensure that **civil society**, as a direct beneficiary of Munich's circular transition, **is consulted and involved in the different stages of the transition.** As such, they can ensure that diverse perspectives, concerns, and needs are considered, leading to a more inclusive and equitable implementation of the City's circular economy strategy.

Actors in private and public finance can help fund the circular transition. Deploying the circular economy on all fronts will require changing production and consumption patterns through, for example, cutting-edge solutions and technologies for production and waste handling processes. Supporting innovation and research and development will also be important, which will require funding. Public funding is becoming increasingly available in Europe to advance the implementation of circular projects on the ground. For example, the EU's Circular Cities and Regions Initiative, of which Munich is part, has launched a Project Development Assistance (PDA) programme to facilitate investment in circular economy projects and initiatives in urban settings, closing the gap between circular projects and investors. Public financing funnelled into these programmes must be met by private funding for long-term impact.

National legislators and policymakers can ensure that concerted efforts extend beyond the city's boundaries. While Munich can engage in dialogue with legislators, its legislative authority remains limited by higher-level legal constraints. Therefore, strong support from German and EU policies will be indispensable in advancing the circular economy agenda. Regulatory backing that addresses inconsistencies, aligns economic incentives with circular goals, supports research and development funding for circular technologies, and harmonises and standardises efforts to ensure transparency and accountability are all areas where higher levels of government support will be vital. Collaboration between local and national governments will be essential to successfully usher Munich into a circular economy and set an example for broader adoption.

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61. This refers to the materials extracted in Germany and directed towards Munich's economy. It must be noted that not all of it is consumed locally; a part is exported, either directly as raw materials, or embedded in products and goods.

62. In this methodology, domestic extraction is one of the key components of the total material footprint. The relationship between the two indicators is explained in the glossary (see Appendix A on pages 100–102).

63. The material flow accounts used in this methodology account for 50 categories of solid, gaseous and liquid materials that flow into and out of an economy. However, air and water embodied (also called 'bulk') in the different materials considered are excluded from the analysis. These include water inflows such as abstractions from natural water bodies (groundwater, surface water, sea) but also collected from the rain, and outflows such as wastewater discharges to rivers and evaporation. Given their enormous mass size in comparison with all other materials (biomass, metals, fossil fuels, non-metallic minerals), these are conventionally excluded from material flows in EW-MFA methodologies. A similar logic is applied for bulk flows of air (nitrogen, oxygen, argon and water vapour) flowing into and out of the economy during combustion processes. However, some specific bulk flows of gaseous material are recorded in the domestic processed outputs to monitor emissions to air from different economic activities (notably greenhouse gases).

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APPENDIX A: GLOSSARY

Consumption refers to the use or consumption of products and services meeting (domestic[335]) demand. Absolute consumption refers to the total volume of either physical or monetary consumption of an economy as a whole. In this report, consumption refers to absolute consumption.

Cycling refers to the process of converting a material into a material or product of a higher (upcycling), same (recycling) or lower (downcycling) embodied value and/or complexity than it originally was.

Domestic Extraction (DE) is an environmental indicator that measures, in physical weight, the amount of raw materials extracted from the natural environment for use in any economy. It excludes water and air. [Source]

Domestic Material Consumption (DMC) is an environmental indicator that covers the flows of both products and raw materials by accounting for their mass. It can take an 'apparent consumption' perspective—the mathematical sum of domestic production and imports, minus exports—without considering changes in stocks. It can also take a 'direct consumption' perspective, in that products for import and export do not account for the inputs—be they raw materials or other products—used in their production. [Own elaboration based on Source]

Economy-wide material flow accounts (EW-MFA) are a 'statistical accounting framework describing the physical interaction of the economy with the natural environment and with the rest of the world economy in terms of flows of materials.' [Source]

Environmental stressor, in Input-Output Analysis, is defined as the environmental impact occurring within the region subject to analysis. There is, therefore, an overlap between the stressor and the footprint, as they both include the share of impact occurring within a region as a result of domestic consumption. This is how they differ: while the rest of the stressor is made up of impacts occurring within a region as a result of consumption abroad (embodied in exports), the footprint includes impacts occurring abroad as a result of domestic consumption (embodied in imports).

Greenhouse gases (GHG) refers to a group of gases contributing to global warming and climate breakdown. The term covers seven greenhouse gases divided into two categories. Converting them to **carbon dioxide equivalents** (CO_2e) through the application of characterisation factors makes it possible to compare them and to determine their individual and total contributions to Global Warming Potential (see below). [Source]

High-value recycling refers to the extent to which, through the recycling chain, the distinct characteristics of a material (the polymer, the glass or the paper fibre, for example) are preserved or recovered so as to maximise their potential to be re-used in a circular economy. [Source]

Materials, substances or compounds are used as inputs to production or manufacturing because of their properties. A material can be defined at different stages of its life cycle: unprocessed (or raw) materials, intermediate materials and finished materials. For example, iron ore is mined and processed into crude iron, which in turn is refined and processed into steel. Each of these can be referred to as materials. [Source]

Material footprint, also referred to as Raw Material Consumption (RMC), is the attribution of global material extraction to the domestic final demand of a city. In this sense, the material footprint represents the total volume of materials (in Raw Material Equivalents) embodied within the whole supply chain to meet final demand. The total material footprint, as referred to in this report, is the sum of the material footprints for biomass, fossil fuels, metal ores and non-metallic minerals. It is composed of the sum of domestic extraction and imports in raw material equivalents, minus exports in raw material equivalents. This allows us to allocate the footprint to the consumption. [Source]

Material flows represent the amounts of materials in physical weight that are available to an economy. These material flows comprise the extraction of materials within the economy as well as the physical imports and exports (such as the mass of goods imported or exported). Air and water are generally excluded. [Source]

Net Extraction Abroad (NEA) represents the difference between the trade balance of products and that of the raw materials needed to produce them. The difference between the two represents the 'actual' or net quantity of raw materials that have been extracted abroad to satisfy domestic consumption.

Planetary boundaries define the 'safe operating space' for humanity, based on the planet's key biophysical processes. Originally developed by Rockström et al. (2009), the framework quantifies nine 'limits': 1. Climate change, 2. Novel entities,[336] 3. Stratospheric ozone depletion, 4. Atmospheric aerosol loading, 5. Ocean acidification, 6. Biogeochemical flows (nitrogen and phosphorus), 7. Freshwater use, 8. Land-system change, and 9. Biosphere integrity.[337] Six of nine boundaries have now been transgressed. [Source]

Raw Material Equivalent (RME) is a virtual unit that measures how much of a material was extracted from the environment, domestically or abroad, to produce the product for final use. Imports and exports in RME are usually much higher than their corresponding physical weight, especially for finished and semi-finished products. For example, traded goods are converted into their RME to obtain a more comprehensive picture of the 'material footprints'; the amounts of raw materials required to provide the respective traded goods. [Source]

Raw Material Consumption (RMC) represents the final domestic use of products in terms of RME. RMC, referred to in this report as the 'material footprint', captures the total amount of raw materials required to produce the goods used by the economy. In other words, the material extraction necessary to enable the final use of products. [Source]

Resources include, for example, arable land, freshwater, and materials. They are seen as parts of the natural world that can be used for economic activities that produce goods and services. Material resources are biomass (like crops for food, energy and bio-based materials, as well as wood for energy and industrial uses), fossil fuels (in particular coal, gas and oil for energy), metals (such as iron, aluminium and copper used in construction and electronics manufacturing) and non-metallic minerals (used for construction, notably sand, gravel and limestone). [Source]

Secondary materials are materials that have been used once and are recovered and reprocessed for subsequent use. This refers to the amount of the outflow which can be recovered to be re-used or refined to re-enter the production stream. One aim of dematerialisation is to increase the amount of secondary materials used in production and consumption to create a more circular economy. [Source]

Sector describes any collective of economic actors involved in creating, delivering and capturing value for consumers, tied to their respective economic activity. We apply different levels of aggregation here—aligned with classifications as used in Exiobase V3. These relate closely to the European sector classification framework NACE Rev. 2.

Socioeconomic cycling is the technical term for the Socioeconomic Cycling metric. It comprises all types of recycled and downcycled end-of-life waste, which is fed back into production as secondary materials. Recycled waste from material processing and manufacturing (such as recycled steel scrap from autobody manufacturing, for example) is considered an internal industry flow and is not counted as a secondary material. In the underlying model of the physical economy used in this report, secondary materials originate from discarded material stocks only. The outflows from the dissipative use of materials and combusted materials (energy use) can, by definition, not be recycled. Biological materials that are returned back to the environment (for example, through spreading on land) as opposed to recirculated in technical cycles (for example, recycled wood) are not included as part of socioeconomic cycling. Energy recovery (electricity, district heat) from the incineration of fossil or biomass waste is also not considered to be socioeconomic cycling, as it does not generate secondary materials.

Socioeconomic metabolism describes how societies metabolise energy and materials to remain operational. Just as our bodies undergo complex chemical reactions to keep our cells healthy and functioning, a city undergoes a similar process—energy and material flows are metabolised to express functions that serve humans and the reproduction of structures. Socioeconomic metabolism focuses on the biophysical processes that allow for the production and consumption of goods and services that serve humanity: namely, what and how goods are produced (and for which reason), and by whom they are consumed. [Source]

Territorial-based carbon footprint is based on the traditional accounting method for GHG emissions, with a focus on domestic emissions, mainly coming from final energy consumption. A **consumption-based carbon footprint** uses input–output modelling to not only account for domestic emissions but also consider those that occur along the supply chain of consumption (for example, accounting for the embodied carbon of imported products).

Total material consumption is calculated by adding Raw Material Consumption (material footprint) and secondary material consumption (cycled materials).

APPENDIX B: HOW THE FOUR CIRCULAR STRATEGIES WORK TOGETHER

There are potential overlaps between some of the four circular strategies: narrow, slow, regenerate and cycle. For example, slow and cycle interventions often work together. By harvesting spare parts to use again, we are both cycling—by reusing components—and slowing, by extending the lifetime of the product the components are used for. And ultimately, slowing flows can result in a narrowing of flows: fewer new replacement products will be needed by making products last longer, resulting in decreased material use. There are also potential tradeoffs between the four strategies to be acknowledged. Fewer materials being used for manufacturing—narrow—means less scrap available for cycling. Similarly, if goods like appliances and vehicles are used for longer—slow—their energy efficiency falters in comparison with newer models, thus preventing narrowing. Using products for a long time—slowing flows—also decreases the volume of materials available for cycling: this can significantly impact material-intensive sectors like the built environment, where boosting the availability of secondary materials is particularly important. What's more: some strategies to narrow flows, like material lightweighting, can result in decreased product quality and thus shorten lifetimes—making it more difficult to slow flows.

APPENDIX C: DYNAMICS INFLUENCING HOW WE MEASURE CIRCULARITY

Applying our Circularity Gap methodology to cities is complex, and has required us to make a number of methodological choices. In a bid to generate actionable insights for local economies, our Circularity Gap Reports take a consumption perspective: we consider only the materials that are consumed domestically, and allocate responsibility to consumers by excluding exports. However, the more 'open' an economy is, calculating the import content of exports becomes more difficult within the material flow analysis and input-output analysis frameworks, the latter in particular.

With our assessment approach, most production is ultimately driven by consumer demand for certain products or services. In an increasingly globalised world, the chain that connects production to consumption becomes more entangled across regions. Demand-based indicators—applied in this analysis—allow for a reallocation of environmental stressors from producers to final consumers. This ensures transparency for countries with high import levels and also supports policies aimed at reducing or shifting consumer demand, at helping consumers understand the material implications of their choices, or at ensuring that costs of, and responsibilities for, resource depletion and material scarcity are allocated to entities and regions based on their roles in driving production processes through consumption.

Considering what residents of Munich consume to satisfy their needs, we must apply a nuanced lens to the direct imports; meaning we work out the full material footprints of the products. To account for the material footprint of raw materials is straightforward, but this is not the case with semi-finished and finished goods. To represent actual material footprints in imports and exports, we apply so-called RME (Raw Material Equivalents) coefficients in this study. As an open, high-income city , doing so in the case of a city like Munich is more complex than for a less integrated city.

Finally, the Socioeconomic cycling metric represents a city's efforts to use secondary materials; this includes waste collected in other cities or countries and later imported for local use. The total amount of waste recycled in treatment operations is therefore adjusted by adding waste imports to—and subtracting waste exports and by-products of recovery from—the amount of waste recycled in local recovery plants. When we adjust the volumes of recycled waste in treatment operations using imports and exports of secondary materials, 'credit' for saving virgin materials is ascribed to the system that uses that secondary material—recovered from former 'waste'. This perspective is similar to national accounts' logic, in which most re-attributions are directed at final use. Whilst Munich's waste management sector has been investing heavily in domestic reuse and recycling infrastructure, the market is not bound by geographical borders and materials can be transported wherever makes logistical, environmental and economic sense. Difficult-to-recycle materials and those that arise in smaller quantities can often be bulked and then transported for treatment in regional facilities. However, it's also possible to take a more 'production-oriented' approach, in which 'credit' for recycling efforts is given to the city that collects and prepares waste for future cycling. This is, for example, the perspective taken by Eurostat in its calculation of the Circular Material Use Rate (at a national level). For more information on this, refer to the Methodology document.

APPENDIX D: PRACTICAL CHALLENGES IN QUANTIFYING CIRCULARITY

The circular economy is full of intricacies: quantifying it in one number presents a number of limitations. These are:

- **There is more to circularity than (mass-based) cycling.** A circular economy strives to keep materials in use and retain value at the highest level possible, with the aim of decreasing material consumption. The cycling of materials measured by the Socioeconomic ycling metric is only one component of circularity: we do not measure value retention, for example. The Metric focuses on the end-of-use and mass-based cycling of materials that re-enter the economy but does not consider in what composition, or to what level of quality. As such, any quality loss and degradation in processing goes unconsidered.
- **Socioeconomic cycling only focuses on one aspect of circularity.** We focus only on material use without examining other factors such as biodiversity loss, pollution, toxicity, et cetera. This reveals the limitations of focusing solely on materials' cycling or on the 'closing-the-loop' effect. Socioeconomic cycling is calculated as the share of secondary materials (numerator) over the total consumption of the urban economy (denominator). In a system with high total material consumption like Munich, increasing material cycling has a much smaller impact on the overall material cycling indicator: the bigger the denominator, the smaller the impact of increasing the numerator is on the overall percentage. This also means that in consumption-driven economies, it is not only important to increase material cycling but also to decrease consumption in order to increase the percentage metric significantly.
- **Relative compared to absolute numbers.** The Socioeconomic Cycling Metric considers the relative proportion of cycled materials as a share of the total material consumption: as long as the amount of cycled materials increases relative to the extraction of new materials, we see the statistic improving, despite the fact that more virgin materials are being extracted—which goes against the primary objective of a circular economy.
- **It is not feasible to achieve 100% circularity.** There is a practical limit to the volume of materials we can recirculate—in part due to technical constraints—and therefore also for the degree to which we can substitute virgin materials with secondary ones. Some products, like fossil fuels, are combusted through use and therefore can't be cycled back into the economy, while others are locked into stock like buildings or machinery and aren't available for cycling for many years. Products that can be cycled, such as metals, plastics and glass, may only be cycled a few times as every cycle results in lower quality and may still require some virgin material inputs. Because of this, reaching 100% circularity isn't feasible: this calls for a more nuanced approach to calculating circularity and setting targets.

APPENDIX E: WASTE MANAGEMENT

Waste statistics of Munich were harmonised with EW-MFA system boundaries such that their scopes match as closely as possible. In particular, the following waste streams were either excluded from the EW-MFA system boundaries or do not count as the socioeconomic cycling: sludges and liquid wastes (accounted for as ecological cycling); animal faeces, urine and manure (accounted for as ecological cycling), waste originating from treatment of waste (secondary waste), soils (do not count as domestic extraction) and dredging spoils (do not count as domestic extraction). These waste streams accounted for 50% of the total waste treated and 53% of what is recycled.

In 2019, 3.34 million tonnes of waste treatment was recorded in Munich, of which 1.66 million tonnes were soils and dredging spoils that do not fall within the EW-MFA system boundaries.[338] Under the system boundary definition of this analysis, 1.67 million tonnes is considered as reported waste, while another 0.03 million tonnes is unreported. Most unreported waste is constituted by the recalculated amount of manure (0.002 million tonnes), the remaining (0.028 million tonnes) being extractive waste. Of the 1.7 million tonnes of waste that's treated, 75% is technical cycling of materials (1.3 million tonnes, of which 0.8 million tonnes come from construction and demolition waste), while the remainder is lost indefinitely. Of the remaining 25%, 18% ends up incinerated (including energy recovery), 5% is landfilled, and 2% is lost, composed in part of waste from energetic use in the form of excreta from human food consumption, which is treated in wastewater treatment plants or spread on land, and is not accounted for explicitly in the Socioeconomic cycling metric. It is rather included as part of the Ecological cycling potential (see page 34 for more information). This difference explains the gap between the rate of domestically cycled materials (75%), which feeds into the Socioeconomic cycling metric, and the traditional recycling rate obtained from traditional waste statistics (53%). When it comes to trade in waste, Munich's situation is underpinned by a negative trade balance in secondary materials: the country is exporting more recyclable waste (0.64 million tonnes) than it is importing (0.51 million tonnes). This, in turn, has a negative effect on the Socioeconomic cycling metric when a consumption-based perspective is taken, as less waste is re-entering Munich as secondary materials.

End-of-life waste is one element of a larger indicator called Domestic Processed Output (DPO), which can originate from both the material use and energetic use of products. DPO is the total mass of materials that have been used in Munich before flowing into the environment—through landfilled waste or as emissions, for example. DPO from energetic use (including food and feed) stands at 15.5 million tonnes and is composed mainly of emissions to air, as well as manure and combustion waste. These emissions can stem from fossil fuel sources (14.6 million tonnes) as well as biogenic origins (0.9 million tonnes). Together with 0.4 million tonnes of DPO from material use (end-of-life waste excluding recycled materials), this adds up to a total DPO of 16 million tonnes. A small part (2,000 tonnes), which originates mostly from energetic use, but partially also from material use, are so-called dissipative uses and losses: materials that are dispersed into the environment as a deliberate or unavoidable consequence of product use. This includes fertilisers and manure spread on fields or salt.

APPENDIX F: ASSUMPTIONS FOR THE SCENARIO MODELLING

Scenario one: Build a circular built environment

1.1 Optimise building stock expansion & increase occupancy rates

In modelling this intervention, we examine a mix of supply and demand-side measures. To model housing stock regulation, we assume that throughout urban planning processes, fewer project approvals are given out that allow for construction with virgin materials. This could be achieved by regulatory and fiscal disincentives on virgin construction materials, thus supporting the uptake of secondary materials, for example. Accordingly, we assume a reduction of new construction by 31%. The restriction is applied to residential buildings only. The cap to the number of buildings is set using the fraction of Construction and Demolition Waste and other mineral waste that is not already recycled (which represents the volume of secondary construction material available) over a share of the net addition to stocks (which is used as a proxy for the material requirements of the housing demand in that year). Under such conditions, the cap is estimated at 99.4% of the residential building demand. Here, the assumption is that a cap based on the physical volume of materials is a good proxy for setting a cap on monetary investments. This scenario implicitly assumes max collection for recycling for construction and demolition waste and assumes 50% of it to be suitable for reuse.[339] Consequently, purchases of waste disposal services by the construction sector are set to 0. This could be enabled by incentivising the use of secondary materials, for example. In order to meet the demand for housing, we boost spending on housing renovation. This could be driven via targeted grants and tax breaks, for example. This is a static 'what-if' intervention that models the impact of long-term circular strategies—spanning 50 years or more—as if they would happen tomorrow without factoring in developments in the underlying socioeconomic trends, such as population changes or efficiency improvements. A combination of measures to increase average occupancy in both residential and commercial buildings was also modelled. For this, a maximum potential increase of 25% and 20% in the occupancy and proportional decrease in footprint of real estate services is modelled.[340] Additionally a reduction in electricity and heating fuels consumption due to increased residential occupancy and commercial space occupation is assumed to be proportional to the decrease in occupied space.

This scenario also comprises a range of strategies to increase building occupancy: these will reduce the total number of buildings needed. To assess this intervention's impact, we model a mix of measures. We assume that incentives for co-housing and multifunctional spaces—such as tax breaks—are enforced. For co-housing and multifunctional spaces, we assume a potential increase in occupancy of up to 25%, and a proportional decrease of 20% in the footprint of real estate services—along with cuts in electricity and heating fuel consumption as a result of increased occupancy. Increasing occupancy could be driven by levying a tax on unoccupied spaces.

1.2 Shape a low-carbon, energy-efficient building stock

Scenario one's second intervention focuses solely on the demand-side circular strategies. It models measures for maximising energy efficiency in the housing stock, such as deep retrofitting. All renovations (i.e. structural, light and medium energy) are carried out as deep energy renovations. This implies that the rate for deep energy renovations is raised from the current 0.1% to 9.9% (the sum of all the other renovation rates).[341] According to EU data,[342] energy savings of 66%, 42%, 13% and 0.2% are assumed for deep, medium, light and structural renovations respectively. Based on this data, average energy savings from current renovations are estimated at around 9% and an overall reduction of the energy need of 57% is therefore applied. It's worth noting, however, that deep retrofitting will come at the cost of extra materials and embodied carbon: it's essential that circularity is prioritised in design and material choices to ensure outcomes are beneficial.

1.3 Shift to resource-efficient building practices

In modelling the impact of this intervention, we make a number of assumptions. For material use in construction, steel, aluminium and cement use is reduced—by 15%, 10%, and 20%, respectively—while the use of regenerative materials like wood increases up by 200% to offset the decrease in concrete; on-site material losses decrease by up to one-fifth while local supply chains are prioritised for material sourcing, reducing the overall transportation required. In households, we assume room temperatures drop by an average of 2-degrees, while smart metering decreases energy consumption by up to 14%. We also assume an increase in the use of energy-efficient washing machines, tumble dryers and irons.

Scenario two: Shift to a circular food system

2.1 Shift to more sustainable food production

This supply-side intervention assumes a shift toward locally produced food in households and in the restaurant sector with a policy focus on national food self-sufficiency. It envisions eliminating the need for chemical fertilisers, pesticides, hot-housing of fruit and vegetables (and thus heating fuels), and transportation services, due to changes in consumer choice towards organic and seasonal produce. In modelling this intervention, we assume a 100% cut in the use of mineral fertilisers, chemicals, and medicines as inputs to food and hotels and restaurant products. We assume a boost in the proportion of local food on the market up to 50%, which is modelled as a 50% reduction of the transport needs of the food industries. Respectively, we assume an increase of 30% in the proportion of seasonal food in the market, which implies reducing the inputs of fuels and electricity to the vegetable sector by 30%. Due to the nature of our methodological approach, we were unable to provide a detailed assessment of changes in land-use management: increased regenerative farming practices, such as agroforestry, or the role of biorefining and the production of sustainable biofuels, for example. However, it's worth mentioning that these can undoubtedly play a key role in advancing circularity and diminishing environmental pressures.[343]

2.2 Cut food waste

For modelling the reduction of waste, the food supply from the FAOSTAT food balance sheets, which are based on purchases, was disaggregated into actual food intake and post-consumer waste. The latter was based on region-specific waste fraction per food group from FAO reports. This strategy assumes Munich's residents maintain the structure of their current diet but reduce their caloric intake to a recommended 2,700 kilocalories per person per day.[344, 345] Moreover, the elimination of avoidable post-consumer organic waste was also considered, up to 50%, as per official targets in line with SDG 12.3.

Scenario three: Advance circular manufacturing

3.1 Implement resource-efficient manufacturing

In modelling this supply-side intervention, we consider a mix of strategies. We assume that metal inputs (all metals) for specific products are reduced by 28% due to process improvements.[346] We also model the impact of implementing industrial symbiosis, which implies reducing yield losses and diverting scrap from the manufacturing industry, to other sectors, thereby reducing their virgin material use. We assume that Munich implements resource-efficient manufacturing techniques such as additive manufacturing and near-net shape manufacturing (NNS). Additive manufacturing, which uses data computer-aided design software to deposit materials in the exact shapes needed, allows for flexible and highly material-efficient production processes. This is particularly relevant for materials such as biochemicals, metals and ceramics in sectors such as aerospace, automotive and medical.[347] NNS allows for a product or component's initial production to be as close to the finished product as possible, thus reducing material inputs, waste material and (procurement, production, and waste disposal) costs.[348] Using waste as raw material could further increase cycling and reduce waste.

3.2 Employ R-strategies for machinery, equipment and vehicles

For this intervention, we first model a mix of supply-side measures. For remanufacturing and refurbishment, we assume that the overall volume of sales remains the same due to the redistribution and re-selling of the remanufactured/refurbished products, thereby creating a new life cycle. The displacement of new sales is therefore modelled as a net reduction in the inputs needed to produce the same volume of product output. When it comes to repair, upgrading and reuse, implementing both supply and demand-side measures would yield greater benefits. This could include new business models based on servitisation (renting and leasing, for example) and more flexible supply chain management (reverse logistics, for example), where manufacturing companies can capture value by returning goods to upstream operations. For instance, companies that sell machinery may decide to rent or lease it out to customers, eventually repairing and/or remanufacturing it to extend its lifetime. For repair, maintenance, upgrading and reuse, we assume a reduction in sales due to the life cycle extension of the repaired/maintained products (thus precluding the need for new purchases). Displacement of new sales can be modelled directly as a reduction in the product output volume. Two cases of repair are distinguished: repair and maintenance performed at the final demand level—where the repair action is carried out by households (leading to no need for extra repair services)—and repair and maintenance performed at the industry level –where the repair action is carried out by companies with extra repair services involved. We apply strategies at the same level across product categories, with the following split: 50% material inputs reduction due to remanufacturing and refurbishment, 25% reduction in material output due to reuse, and 12.5% material output reduction for repair and 12.5% for maintenance and upgrade.

Scenario four: Promote a circular lifestyle

4.1 Embrace a 'material sufficiency' lifestyle

For this intervention, we have modelled a range of strategies. The consumption of new textile products is cut by 50%. For new textile purchases, items with recycled fibres or that are durable and high quality are preferred. We also assume that furniture purchases are minimal and done locally. Also, where possible, residents buy items designed for reparability (with replacement parts available in case of breakage) and made with reused and redesigned furniture components. Spending on electrical and electronic appliances such as radios, televisions and computers is cut by 80%. Paper use is heavily decreased, by printing only what's needed, buying recycled paper and toilet paper, and increasing digitalisation (through e-books, for example). We also assume that a material-sufficiency approach is applied to the service sector. Accordingly, we assume that a segment of the population becomes highly dependent on inter-community exchange and low use of commercial services. For example, people depend more on community members than commercial services for rental, repair, and reuse, and frequently work unpaid within their local community (for example, exchanging services through time banks). Finally, we assume that local cultural activities and home-based hobbies like gardening are preferred to long-distance travel.

Scenario five: Redesign mobility

5.1 Reduce or avoid travel, or the need to travel

Reduce air travel

We assume a reduction in air traffic in congested regions with specified limits. Households' demand for air mobility services is reduced by capping the number of trips per capita per year from 3.3 to 2.5 for a net reduction of 24%. No reduction in tourism-related activity is modelled (for example, Hotels and Restaurants) as this is assumed to be offset through a rebound in spending on local tourism activities.

Reduce reliance on private vehicles

This intervention models the impact of several demand-side measures: one-quarter of mobility by car is eliminated and reallocated to bicycle use (15%) and walking (10%). The remaining 75% of the total is reallocated to car sharing and carpooling. This results in an increase in average vehicle occupancy—up from 1.3 to 2.5. This is partially mitigated by greater 'wear and tear' for vehicles due to higher utilisation (+25%). It is also assumed that the elimination of the car extends to the elimination of the need for manufacturing and selling the car on top of the obvious reduction in fuel use.

Pursue a modal shift for transport

In modelling a modal shift, the population is divided into segments and their demand for mobility goods shifts towards other options. The main options represented in the model are buses and railways, respectively, representing a relevant share of urban and extra-urban public transport. A reduction of passenger kilometres represents the shift towards walking and biking. This can be realistically modelled by considering the actual potential in the shift of passenger kilometres from private to public transport. In modelling this intervention, we assume that 45%

of passenger kilometres currently travelled by car are proportionally redistributed to journeys by bus and urban rail. In the medium term, this intervention will require spending on infrastructure to accommodate the increasing demand for public and shared mobility.

Embrace flex work

This intervention envisions reducing the need for mobility by working from home, especially for hires living far from work. Energy rebound does not apply because the consumption is occurring at home rather than at the office, whereas the cost of ICT equipment is assumed to stay with the employer. In modelling this intervention, we assume that flex work increases by 50%, matched by a reduction in commuter transport by car, bus and train. We also assume that demand for commercial real estate will drop as more workers stay at home.

5.2 Drive cleaner mobility forward

Improve vehicle design

We assume that vehicle design can reduce the demand for steel and aluminium components by 50% for private cars and vans, and steel, copper, and aluminium by 17% for trains. A reduction in fuel and energy consumption stems from this improvement and it is modelled as ancillary change.

Electrify mobility

The electrification of mobility is modelled as a shift in fuel consumption, from gasoline and diesel to electricity. We apply this change to half of private vehicles and all public buses. Our model considers the fuel efficiencies of both Internal Combustion Engine and Electric cars and buses, as well as fuel and power prices, while production changes (such as the manufacturing of batteries) are not explicitly modelled.

APPENDIX G: MODELLING THE IMPACT OF COMBINED SCENARIOS

Overlaps between—and the sequentiality of—interventions mean that our combined scenario calculations, as laid out in Chapter four, yield different results than simply adding up the impacts of individually modelled interventions. In particular, the scenarios on repair, recycling, as well as fossil resource consumption, are applied across sectors, thereby also influencing industry-specific interventions on agriculture and construction, for example. Therefore, we prioritise interventions according to the principles of the circular economy. We begin with strategies that aim to reduce inputs, secondly applying repair and reuse-focused strategies, and only lastly applying those focused on recycling. We look at overlaps in terms of coherence, meaning that we exclude interventions that explicitly contradict each other. We also don't take anti-synergic effects into account: for instance, the reduced availability of waste for recycling as a results of improved manufacturing efficiency. The sequential application of interventions means that those applied further down will have a lower impact than earlier ones, targeting the same transactions between economic actors. For example: let's assume we model two interventions targeting investments in the construction services sector. The share of the investment to be reduced—as specified in the first intervention—will be applied to the original investment figures. In contrast, the second intervention will be applied to the reduced investment figure that has resulted from the application of the first intervention. It's worth noting that all scenarios are expected to have some rebound effects, yet for the most part we are unable to calculate these, aside from those outlined above.

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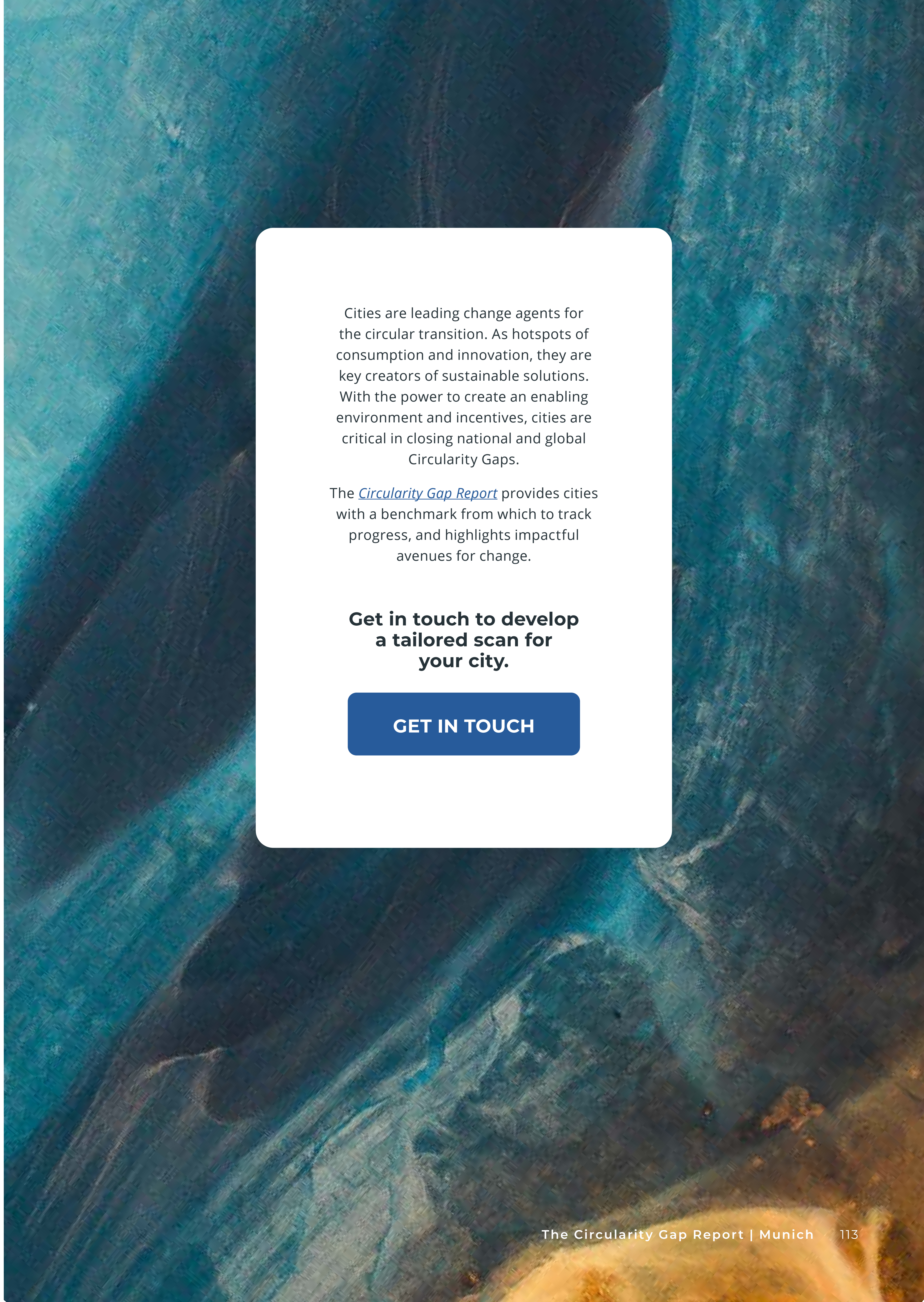

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