UN environment programme

International Resource Panel

# RESOURCE EFFICIENCY AND CLIMATE CHANGE

## Material Efficiency Strategies for a Low-Carbon Future

### Implications for Business Leaders in Housing and Mobility

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Implications for Business Leaders in Housing and Mobility

# Resource Efficiency and Climate Change

## Material Efficiency Strategies for a Low-Carbon Future

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# About this document

This document highlights and contextualizes findings from the International Resource Panel report *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*. It provides a starting point for strategic decision-making for businesses in urban design, building and mobility. It has two concrete objectives:

- To highlight the key scientific findings and direct implications for business leaders of the above-mentioned IRP report.
- To contextualize the findings from said report with ideas from business for business about the economic opportunities of material efficiency strategies.

# Key Messages

Credit: Flickr/CC BY 2.0/Carbon Visuals, One day's carbon dioxide emissions from above

The IRP Resource Efficiency and Climate Change (RECC) model shows that effective climate action must combine clean energy strategies with material efficiency strategies. It describes seven material efficiency strategies (Box 2) that hold great potential for climate change mitigation. These strategies may also enable lasting business success in housing and mobility markets, but this potential is still largely overlooked in climate and business debates. Business leaders will benefit from innovating in this field.

The IRP RECC report focuses on G7 countries, India and China as major global emitters, but the strategies are relevant globally.

The scientific findings have direct implications for business leaders:

1. Housing and mobility businesses can boost their climate performance with material efficiency strategies. These strategies have the significant potential to reduce life cycle emissions from homes in the G7 by 35-40 per cent, and by 50-70 per cent in India and China in 2050. For cars, these reductions could be 30-40 per cent in the G7 and 20-35 per cent in India and China.
2. The more intensive use strategy has distinct potential among the seven strategies. By avoiding underutilized floor space and underutilized vehicle capacity, this strategy reduces emissions from the material cycle and from the energy used in heating, cooling and transport. This strategy can deliver a share of over two thirds of the total emission reductions from material efficiency strategies.
3. It is time for all businesses to embrace fundamental business model transformations to fully benefit from material efficiency strategies. Business models that base their revenue on the performance of residential and mobility solutions over their life cycles can benefit from the savings and more innovative design of material efficiency strategies.
4. Material-efficient businesses need, and can support, determined policy development to create enabling market conditions. Important policy instruments include building codes and standards, green public procurement, virgin material taxes, recycled content mandates and the removal of virgin material subsidies.

In Chapter II, innovators in the business community provide ideas on the economic opportunities of material efficiency strategies.

Material efficiency strategies are essential in the effort to turn rising pressures into lasting business success. With consumers demanding more convenient and sustainable mobility and housing, with prices and price volatility of materials rising, with digitalization becoming the new normal, and with the devastating effects of the climate, nature and pollution crisis becoming more visible, lasting business success requires providing material-efficient services instead of resource-intensive products.

- In housing, material efficiency strategies can help:
  - Increase productivity of existing stock
  - Meet new demand and save costs in new construction
  - Meet the demand for new living services across old and new buildings
- In mobility, material efficiency strategies are essential in:
  - Meeting consumer demand for more convenient, affordable and flexible mobility
  - Capturing more value per vehicle
  - Staying relevant by meeting societal expectations of better socioeconomic performance and safety

To seize these opportunities, businesses can take several steps, with a focus on cooperation and promoting policy development:

- Anchor business visions in sustainable resource management and climate science.
- Invest in innovative pilots to determine scalable business models in material-efficient housing and mobility.
- Demand and support policies to create the market conditions necessary for material-efficient businesses to prosper. Reshape old and join new coalitions to overcome hurdles that cannot be tackled alone.

In the context of the COVID-19 pandemic and economic recovery in which this document is being written, material-efficient business models can identify important areas for recovery investments to boost economic activity and jobs while promoting a decoupled and more sustainable economy. At the same time, business models will need further refinements that consider infection prevention and resilience.

# Content

## **Box 1**. A note on terminology

- **Circular economy:** An economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized (IRP 2020).
- **Decoupling:** When resource use or some environmental pressure either grows at a slower rate than the economic activity that is causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling) (IRP 2019b).
- **Decoupled business model:** A business model where revenue is increasingly independent of (i.e. decoupled from) growth in the quantity of virgin material inputs used throughout the value chain (IRP 2019a).
- **Energy measures:** Emission reduction solutions in energy production, e.g. renewable energy sources such as wind or solar, or in direct energy consumption including electrification or fuel switching as well as energy efficiency measures such as more efficient motors or housing insulation.
- **Material cycle emissions:** Emissions associated with producing and processing materials, including credit for replacing primary materials when recycling at the end of life of a product, and for the storage of carbon in wood (IRP 2020).
- **Life cycle emissions:** The emissions associated with the entire life cycle of a product, including material production, construction, operations and disposal. Includes credit for replacing primary materials when recycling at the end-of-life of a product, and for the storage of carbon in wood. also labelled as 'systems-wide' emissions. Here, they refer to the system-wide emissions associated with the production, operation, and disposal of the entire modelled product stock (IRP 2020).
- **Resource efficiency:** Efficient use of resources including materials, water, energy, biodiversity, land and, in the context of climate change, financial resources (IRP 2020).
- **Material efficiency:** The pursuit of technical strategies, business models, consumer preferences and policy instruments that would lead to a substantial reduction in the production of high-volume, energy-intensive materials required to deliver human well-being; expressed as a ratio of the amount of product or service obtained by unit of material use (IRP 2020).
- **Material efficiency strategy:** A unique approach to improve material efficiency across the system.
- **Rebound effect:** When improved efficiency affects demand and leads to an overall increase in consumption relative to a baseline and the benefits of efficiency are partially or fully negated through behavioural or systemic responses (IRP 2020, Chapter 3.5.4).


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# I. The climate benefits of material efficiency

## A. Material efficiency strategies in housing and mobility

The world has roughly 30 years to bring net greenhouse gas emissions to zero, and the curve of current trends must bend fast (United Nations Environment Programme 2019). We are therefore entering the make-or-break decade to make fundamental changes in how we live, move and do business.

Strong climate action is increasingly important for businesses to keep their customers and meet increasing regulation to decarbonise. It is also becoming crucial for investors as central banks have begun considering climate change as a risk to financial stability (Coppola *et al.* 2019; Shrikanth 2020; Townsend 2018).

Debates about emission reductions in industry have mostly focused on using cleaner energy from wind or solar technology, and on promoting energy efficiency, usually meaning the efficient use of fuel or electricity by industrial processes or the end users. While these energy measures are indispensable, they are not enough on their own to reach the goal set by the Paris agreement to keep the global temperature increase below 1.5oC (IRP 2020; IRP 2019c).

Global material production is responsible for about 23 per cent of global emissions today and rising fast. Using clean energy in these processes is relatively difficult. Adding solutions for reducing material consumption is crucial (IRP 2020).

Material efficiency strategies reduce the need for materials (metals, cement and other non-metallic minerals, plastics, rubber and wood) in the provision of goods that provide the same or higher performance for customers and society. In residential buildings and passenger vehicles these strategies include the efficient use and reuse of materials as well as their more efficient operation. In addition, material efficiency strategies not only reduce the need for emissions-intensive new materials but can also reduce energy use for fuel and heating or cooling.

The IRP Resource Efficiency and Climate Change (RECC) model shows that effective climate action must combine clean energy strategies with material efficiency strategies (IRP 2020). Box 2 summarizes the seven material efficiency strategies for climate action.

## **Box 2**. Seven material efficiency strategies for climate action

### Using less material by design

Designing lighter and smaller products that deliver the same service, reduces the amount of materials incorporated in the product and often the energy required to operate the product as well. In this report, we address both the construction of lighter structures (less steel and concrete in the bearing structure of multifamily buildings) and the downsizing of vehicles, i.e., the shift from large vehicles (light trucks, sports utility vehicles) to smaller ones (passenger cars, minicars).

### Material substitution

Replacing cement and steel with wood in buildings and steel with aluminium in cars can reduce life cycle emissions. The mechanisms of emission reductions vary. While wooden structures require less carbon in the construction and even store carbon, aluminium in cars causes an increase in material-related emissions but reduces operational energy use, resulting in a reduction of life cycle emissions.

### Fabrication yield improvements

Reducing material scrap used in the fabrication and manufacturing process can decrease the demand for material input. For example, reduction of trimmings or amount of machining needed in car manufacturing.

*Source:* IRP RECC 2020

**More intensive use**

It implies that less product is required to provide the same service. In the case of vehicles, ride sharing (car-pooling) and car sharing imply that fewer vehicles are used more intensively to provide transport services to a given population. For buildings, both higher utilization rates, e.g., through shared housing, smaller, more efficiently designed residential units, and increased household size/cohabitation can achieve a reduction of building space required.

**Enhanced end-of-life recovery and recycling of materials**

This increases the amount or quality of secondary materials available, which can reduce the amount of primary materials used to produce the same or another product. More of the materials in homes and cars can be recycled but it may require more dismantling/deconstruction to avoid contamination of the different material flows.

**Recovery, remanufacturing, and reuse of components**

Replacing production of spare parts or even primary products. For example, I-beams of buildings can be reused.

**Product lifetime extension**

Through better design, increasing repair, and enhancing secondary markets. For example, the lifetime of buildings can be enhanced through flexible design which makes it easier to modify interior walls, thus accommodating changing use patterns.

In 2015, construction and manufacturing each accounted for 40 per cent of global material-cycle greenhouse gas (GHG) emissions, which are the emissions from the extraction and processing of materials, minus credits for recycling and carbon storage. Residential buildings are responsible for the largest share of construction-related emissions, and cars for the largest share of emissions related to manufacturing. Material efficiency strategies have significant potential to contribute to the reduction of GHG emissions in the housing and mobility sectors (IRP 2020).

The IRP RECC model shows that the material efficiency strategies in Box 2 could reduce 2050 emissions from the material cycle of old and new residential buildings in the G7 by at least 80 per cent. In China, the potential reduction is similar, and in India a bit smaller while still over 50 per cent. For passenger cars, these strategies could reduce material cycle emissions by 57-70 per cent in G7 countries and 29-62 per cent in China and 39-53 per cent in India (Figure 1 and Figure 2, see orange areas) (IRP 2020)

In addition, material efficiency strategies not only reduce the volume of materials used and their related emissions, but also help reduce ongoing energy use – fuel used in cars and energy used for heating or cooling in homes – particularly through the more intensive use strategy (IRP 2020)

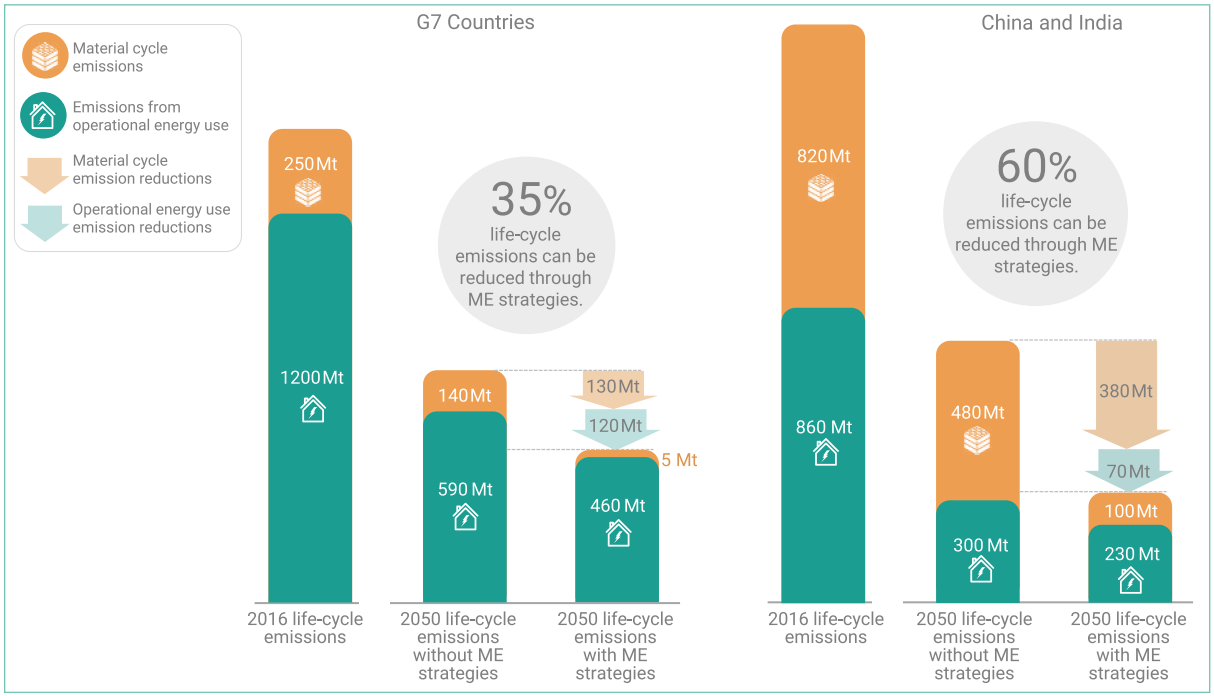
The seven material efficiency strategies together could reduce annual life cycle emissions from homes in 2050 by 35-40 per cent in the G7, and in China and India by as much as 50-70 per cent (Figure 1).

## **Box 3**. A note on the IRP RECC model

The IRP RECC model compares two future scenarios for the 2016–2050 period. The reference scenario without material efficiency strategies (middle bars in Figures 1 and 2) projects the development of emissions for homes and passenger cars with implementation of energy measures only. The material efficiency scenario (right bars) projects how emissions will develop if energy measures and all material efficiency strategies are implemented. The additional reductions through material efficiency strategies are significant, albeit not enough to stay within the 1.5°C limit, which calls for net zero global emissions by 2050. Hence, both energy measures and material efficiency strategies must be implemented even more widely and deeply than what the IRP RECC model suggests. For complete descriptions of the assumptions and the model, please refer to the full report at www.resourcepanel.org/reports/resource-efficiency-and-climate-change.


Credit: Zsolt Biczo/Shutterstock.com

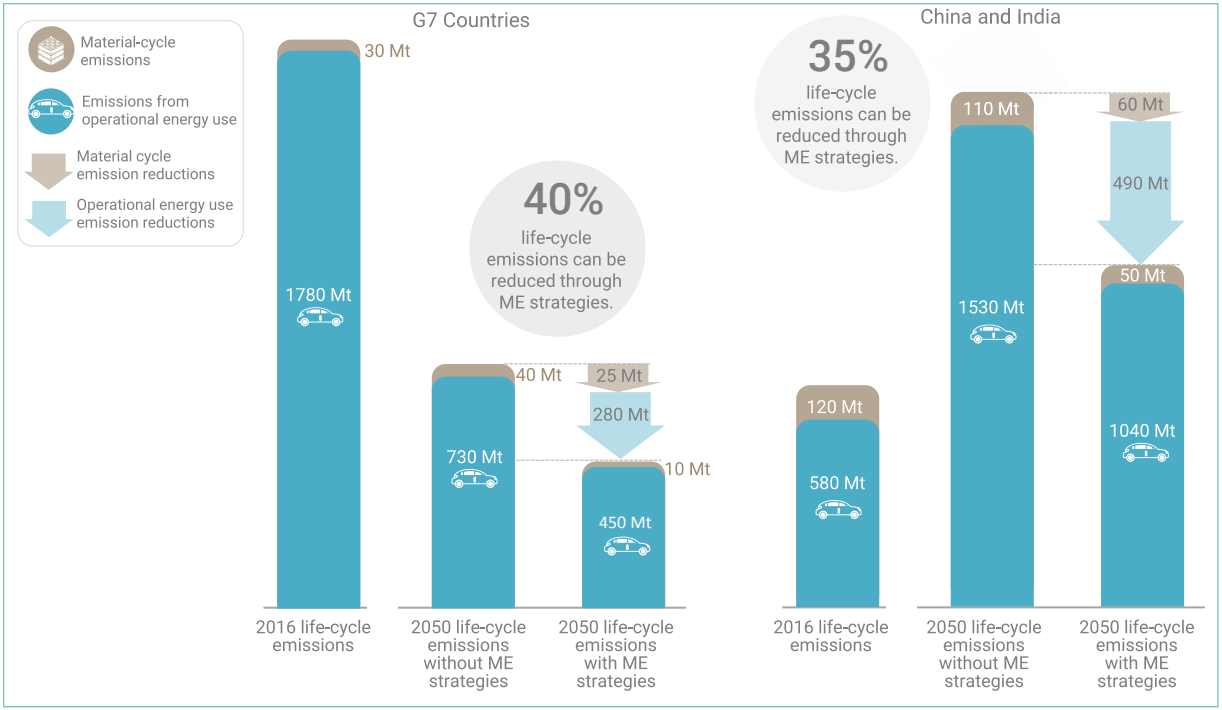
**Figure 1.** Life cycle emissions from homes with and without material efficiency strategies in 2050 in G7 countries, China and India




*Source:* IRP RECC 2020

Reductions in life cycle emissions from cars in 2050 would be 30-40 per cent in G7 countries, and 20-35 per cent in India and China (Figure 2). These reductions are in addition to the emission reductions that come from the anticipated shift towards electric and fuel cell vehicles and decarbonization of the electricity mix. This document focuses on housing and mobility, but similar strategies are likely to be valid for other material-intensive sectors.

**Figure 2.** Life cycle emissions from cars with and without material efficiency strategies in 2050 in G7 countries, China and India




*Source:* IRP RECC 2020


Credit: Pavel Vinnik/Shutterstock.com

## B. The distinct potential of the more intensive use strategy

Of the seven material efficiency strategies modelled by the IRP, more intensive use has the highest potential to reduce emissions in G7 countries. This strategy reduces material cycle emissions—from raw materials extraction and manufacturing—and emissions from fuel use in cars and heating and cooling in homes.

In principle, the more intensive use strategy reduces floor space per capita across the housing stock of a country or reduces the number and size of cars while providing a similar or better level of service (Box 2). On-the-ground studies and experimentation are required to take advantage of this strategy in practice, particularly in the housing sector where the stock is slower to change.

Several approaches to more intensive use are, however, already known or plausible, and provide a starting point for innovation. New forms of car-sharing and ride-pooling services are becoming increasingly popular in cities. More intensive use in housing can mean that people move into space-appropriate residences, downsizing or upsizing with changing family size. Such movements would open space for growing families that need more room, precluding the need for new buildings and hence saving materials, and would also mean that less underused space would be needlessly heated. Multiparty residences (housing for two or more families), such as flats in apartment blocks, tend to be much more space efficient than single family residences, and more heating efficient as walls are shared. In addition, multiparty residences not only save materials and heating, they also provide the possibility of reducing urban sprawl and commutes, which are big factors for emissions and can be detrimental to the economic performance of a city.

Moving towards more intensive use usually requires businesses to provide a different service and consumers to live or move differently, and so requires vision and incentives. Information technology can enable or enhance the opportunities to move in this direction, and businesses will need to innovate in close interaction with consumers.


Credit: Patipong Kantavong/Shutterstock.com

While more intensive use is important, businesses should combine this strategy with other material efficiency strategies, such as material substitution or recycling, to realize the synergistic potential.

The following sections summarize the mitigation potential as modelled by the IRP.

## 1. The climate mitigation potential of more intensive use and other strategies in homes

A 20 per cent reduction in floor space in G7 countries (compared to the reference scenario of 2050) would result in about a 30 per cent reduction of the annual life cycle emissions from homes in 2050. This significant saving is in addition to energy measures such as improving low-carbon heating supply and insulation. The model also tells us that cumulatively for the years from 2016 through 2060, more intensive use could reduce emissions by about 15 per cent, or more if implemented faster. This reduction represents over three quarters of the total reduction potential through material efficiency (see purple area in Figure 3) and makes this strategy a priority for climate action for business leaders in G7 countries.

In China, more intensive use represents roughly half of the potential material efficiency savings, and in India roughly one quarter (Figure 3). India already has a very intensive use of its limited floor space. More intensive use does not mean a reduction from current levels, but only that floor space would grow more modestly than in the reference scenario. In developing countries, the greater need for new buildings – as opposed to working with the existing building stock – suggests that developers and construction businesses should pursue material efficiency strategies that make new construction more efficient. These strategies may include material substitution (for example with sustainable timber) using less material by design – leaner walls and beams, for example – and pursuing fabrication yield improvements through modular offsite fabrication.

In G7 countries with large existing housing stocks and shrinking populations, reducing floor area through more intensive use means demolishing some obsolete buildings. This is where an opportunity to combine strategies comes in. Businesses specializing in enhanced end-of-life recovery and recycling and in recovery, remanufacturing and reuse of components will be needed to enhance more intensive use strategies. These businesses can take care of deconstructed material and components, and design refurbishments and new buildings that use recovered material. Businesses and developers should intensify the use of energy-efficient and modular refurbishments or new buildings.

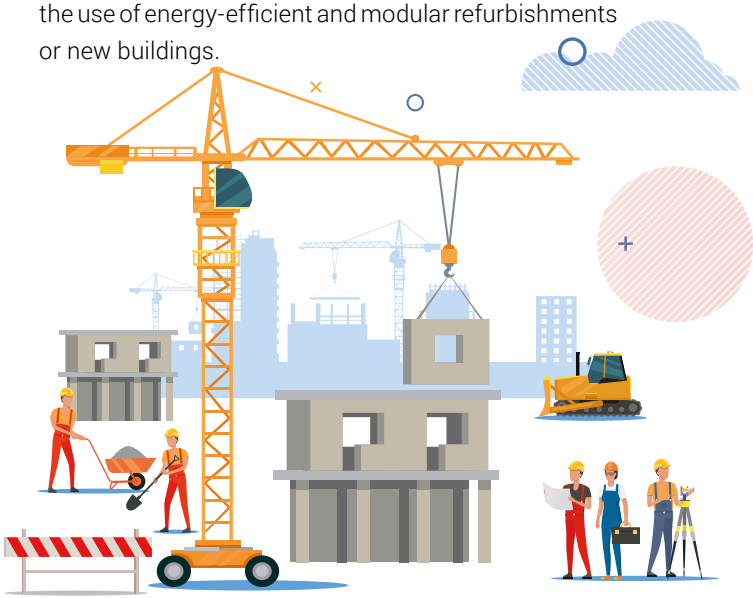
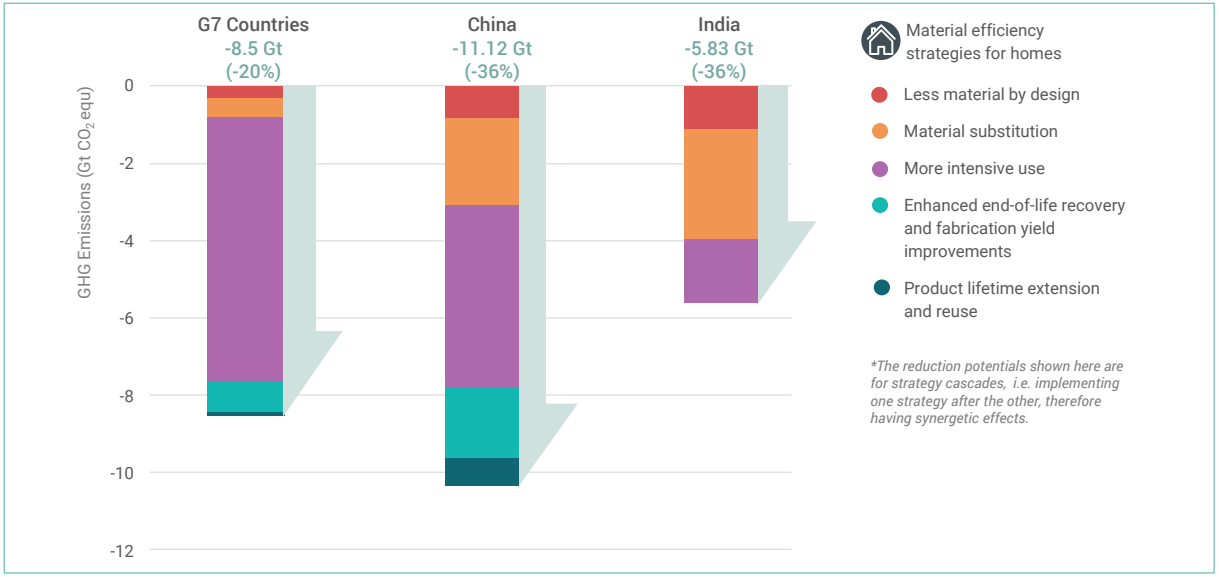


**Figure 3.** Potential GHG savings per material efficiency strategy for homes, cumulative 2016-2060




Note: These figures show cumulative reductions from 2016 through 2060 in comparison with the reference scenario, while figures 1 and 2 show annual reductions in 2050. The relative importance per strategy is similar in annual or cumulative perspectives.
*Source:* Adapted from IRP RECC 2020


Credit: Jason Finn/Shutterstock.com

## 2. The climate mitigation potential of more intensive use and other strategies in cars

In the G7, more intensive use of cars could reduce annual life cycle emissions in 2050 by about 31 per cent and cumulatively for 2016-2060, by about 15 per cent, or more with faster implementation (car-sharing and ride-sharing; see light and dark purple areas in Figure 4). More intensive use represents about two thirds of the total reductions possible through material efficiency, a clear priority for action.

This 15 per cent reduction could be achieved if 25 per cent of all trips were conducted as shared rides and 15-25 per cent of cars in the fleet were shared vehicles by 2050. Car-sharing and ride-sharing, produce positive efficiency effects because they increase the number of people using a car at the same time or over a period of time. Individual 'taxi-type' ride-hailing services do not currently show a net positive efficiency effect given low occupancy and empty trips to the pickup point.

In China and India, life cycle emissions from car fleets are projected to rise from today's levels even with ambitious energy and material efficiency measures. Material efficiency, however, along with electrification, can reduce the emission growth rate. More intensive use plays the largest role in achieving this. Business leaders should promote shared mobility models, which can also significantly contribute to better traffic functioning and reduced air pollution, especially when complementing public transport.

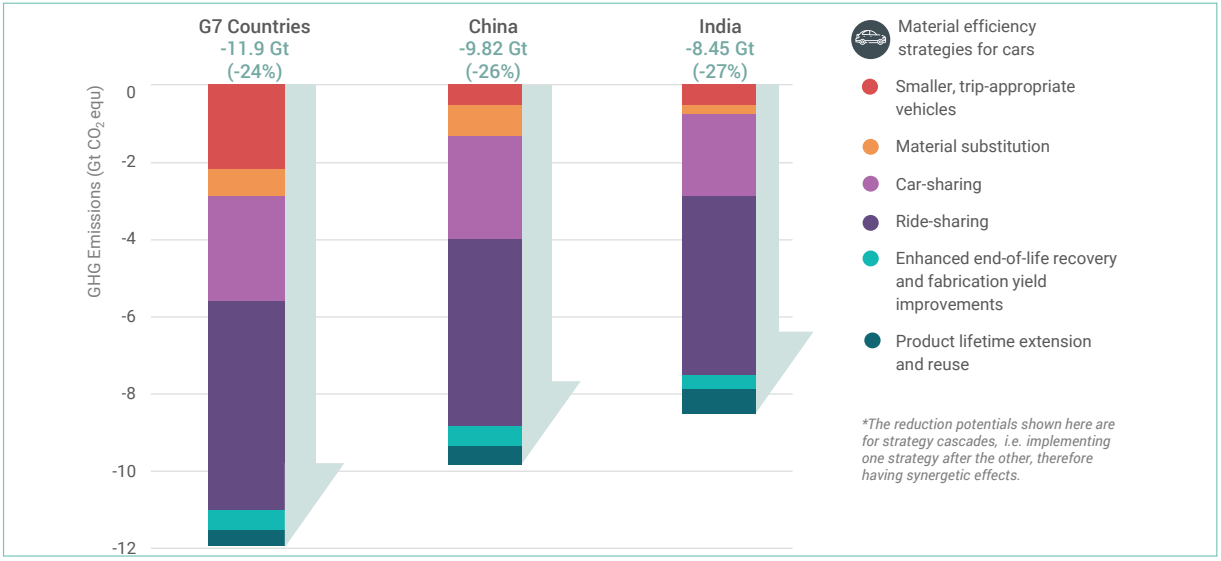
The modelling makes conservative assumptions about the level of sharing. The technical possibility and market importance are much higher. Business leaders should therefore aim for a faster and more ambitious intensification use rate per vehicle.

In populated areas, buses and railways could achieve higher energy and material efficiencies than private cars, even if the cars are shared. Business leaders must, therefore, plan shared cars as complementary, and likely best in cooperation, with mass transit providers within a strategic densification scheme[1].

Credit: Sebastien DURAND/Shutterstock.com

1- According to the IRP, strategic densification is "the process of intensifying the number of jobs/people/amenities located within a network of primary and secondary high-density nodes that are well-connected by efficient and affordable mass transit systems (bus, rail, nonmotorized)". See IRP (2018).

**Figure 4.** Potential GHG savings per material efficiency strategy for cars, cumulative 2016-2060




Note: These figures show cumulative reductions from 2016 through 2060 in comparison with the reference scenario, while figures 1 and 2 show annual reductions in 2050. The relative importance per strategy is similar in annual or cumulative perspectives.
*Source:* Adapted from IRP RECC 2020

## **Box 4**. Authors' perspective on COVID-19

In the context of the COVID-19 pandemic, risk assessments and design must be refined when it comes to denser residential housing and shared mobility.

More intensive use in housing does not mean cramped housing or further density in already overly dense residential areas. Implementing this strategy eliminates underutilized spaces or puts it to better use and creates more efficient and more flexible housing structures. In principle these measures would enable higher quality housing for more people and provide opportunities for community interactions in a well-organized – and safe – manner. If necessary, isolation at home should be possible and even easier, given the higher quality of well-designed and well-maintained, possibly serviced, housing structures. Essential services could be better accessed in more compact neighbourhood set-ups, ideally designed with a well-balanced mix of residential, public and commercial spaces.

For shared vehicles, considerations are potentially more complex given the size of vehicles – and measures to design pandemic-proof shared mobility systems warrants further discussion. Mobility has gone down in all forms during the lockdowns, and customers have been cautious of shared mobility (McKinsey & Company 2020b). Most shared cars or even pooling services, however, are flexible enough to be used individually and can provide alternatives to mass transit options for key workers without obliging people to buy their own car in times of crisis. Some mobility providers have even offered discounts for key workers during the peak of the pandemic in 2020 (CoMoUK 2020). Early observations suggest that with sanitary safety measures in place, shared mobility will likely see a renewed demand from customers soon (McKinsey & Company 2020b). Businesses would do well to look beyond car mobility though, as bicycle and scooter services seem to be in high demand (McKinsey & Company 2020a). Integrated mobility planning tools, and the businesses providing related solutions, are likely to become more important. Flexible mobility systems and booking platforms that respond to social distancing requirements will likely become important in the longer term (WEF 2020).


Credit: Mila Supinskaya Glashchenko/Shutterstock.com

### 3. Fundamental transformation of the business model

There are many opportunities to improve material efficiency over the life cycle of homes and cars. A business model focused on one-off sales of products will not often capture these gains. A business model making revenue from the performance of a product or service over a longer period will. Thus, many businesses need to change to a service-based model that charges for the long-term functionality of homes and cars rather than the sale of the product, incentivizing the minimization of resource use for the duration of the service, an approach dubbed "decoupling business models" (IRP 2019a).


Credit: rodho/Shutterstock.com

## C. Policy action for material-efficient businesses

Much of the required shift in business models needs favourable policy conditions, particularly to achieve a transition at scale. The extensive IRP RECC policy review identifies a gap of material efficiency policies in the G7. Current policy and market conditions are not incentivizing the uptake of material efficiency strategies, and in some cases even actively disincentivizing them.

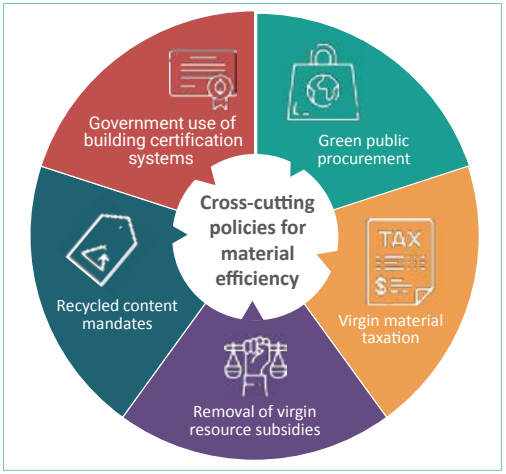
In some North American cities, regulations limit construction permits to single-family houses preventing the construction of efficient modern multiparty residences. Few building codes promote the use of lightweight structures, material substitution, modular building components, deconstruction or recycling. In the vehicle sector, some policies encourage car-sharing to reduce congestion and material recycling to reduce waste, both of which provide useful experience for further policy development. But few policies target more intensive use systematically as a climate mitigation measure or focus on reducing the absolute material cycle emissions in car design.

Worse yet, policy measures such as subsidies for virgin resource extraction are skewing the market against efficiency, artificially lowering the price of virgin materials and limiting the value of potential material savings. Overall, the IRP RECC policy review suggests the need for a life cycle approach to policy design and monitoring. It is tempting to focus on material efficiency policies only at end of life, but the climate change benefits are most likely to be harnessed effectively if policies are developed and evaluated using a life cycle approach.

Increased intensity of use shifts the focus of policy from choice and use of materials to lifestyle choices. Policy instruments such as taxation, zoning and land-use regulation play a role, but so do consumer preferences and behaviour. Cross-cutting policies could have significant impacts on material efficiency. Such policies include building codes and standards green public procurement, recycled content mandates, virgin material taxation and removal of virgin resource subsidies.

Fiscal policy instruments are important in minimizing the rebound effects of monetary savings leading to an increase in consumption. Policy instruments that directly or indirectly raise the cost of production or consumption such as taxes or cap-and-trade systems can reduce rebound effects. While politically challenging, the reduction of subsidies for virgin resources is likely to provide dual benefits – increased material efficiency and government revenues. Moreover, material efficiency measures could be integrated into national planning, including in the Nationally Determined Contributions of the Paris Agreement (NDCs). Figure 5 summarizes important overarching policy instruments identified by the IRP 2020 report.

Figure 5. Cross-cutting policies to improve material efficiency and integration with climate policies




*Source:* IRP RECC 2020 Summary for Policymakers

Business experimentation, evaluation and regular exchange with policymakers will be key elements in informing policy design that increases efficiency, avoids rebound effects and can be implemented at scale by innovative companies.

Credit: ESstock/Shutterstock.com

# II. Ideas from business for business: Commercial opportunities for material efficiency

The IRP RECC model shows that material efficiency strategies bring a range of untapped climate change mitigation opportunities to the housing and mobility sectors. These strategies can also help businesses create a business model that is less dependent on resource use. Businesses are experiencing a new set of market conditions: rising consumer demand for new convenient mobility and housing, volatile and rising material prices, new opportunities of digitalization for smart design and material tracking, and emerging threats from climate change. In this context, material efficiency strategies can help shape durable business success, where more intensive use of buildings and vehicles becomes central.

In many cases, deep business model innovation will be needed to realize the potential mitigation and economic benefits of material efficiency. This chapter presents ideas from business organizations with reference to the relevant chapter of the main report.

The examples in Boxes 5 to 12 illustrate cases of notable innovation. These cases are intended to inspire rather than provide evidence or show a comprehensive picture of the implementation of all material efficiency strategies. Similarly, references to current journalistic sources or advisory reports are meant to illustrate ideas for possible business opportunities, not provide evidence. For evidence-based results, please refer to the IRP RECC 2020 report.

## A. Business opportunities for material-efficient housing

This section outlines business approaches and opportunities for material efficiency in housing. More intensive use is the priority strategy in G7 countries, which should be complemented by the additional benefit of other strategies.

### 1. Increase productivity of existing stock[2]

As populations decline while new building stock grows, G7 countries have large housing stocks with underused space. One priority is therefore to use existing buildings more efficiently in order to increase economic productivity of the existing stock and significantly reduce GHG emissions. One way to use

2- Based on IRP RECC 2020, Chapters 2.3 and 3.3.3

these buildings more efficiently is by repurposing under used commercial and residential space, an effort that can combine more intensive use; recovery, remanufacturing and reuse of components; as well as product lifetime extension.

Developers, property managers and refurbishing businesses in high-demand housing markets such as New York or London can repurpose under used buildings for higher utilization, such as turning former warehouses into residential space (Savills UK News 2019). Applying the product lifetime extension strategy through repurposing old buildings in G7 countries reduces emissions only if paired with refurbishment to improve insulation and heating efficiency.

More business creativity – and policy cooperation – is needed to make a business case for increasing the utilization of under used investment properties, second homes or housing stock inefficiently reserved for short-term occupancies.

## **Box 5**. Retrofitting for more intensive use and energy efficiency

**3XN Architects – Quay Quarter Tower, Australia**

The Quay Quarter Tower in Sydney, designed by 3XN Architects, Arup, and BVN, used materials from an existing structure on the site to make significant economic and environmental savings. According to 3XN reports, 65 per cent of columns, beams and slabs, as well as 95 per cent of structural walls were reused in the redesign of the building. In total, 50 per cent of the resources for the new tower were directly reused from the old one. 3XN reports that by reusing materials, they averted a total of 7,505 tonnes of CO2 in emissions, equivalent to 2,500 one-way flights from Sydney to Copenhagen (3XN 2019).

Source: 3XN website 2019. https://gxn.3xn.com/wp-content/uploads/sites/4/2019/01/Building-a-Circular-Future-3-3.pdf

While the optimization of existing housing stock in high-demand cities is an intuitively appealing option, these places already have high utilization rates on average, and the potential to increase it might be limited. But declining populations in cities or rural regions in G7 countries have underutilized residential space (Der Deutschlandatlas n.d.; UK Government 2020), and in these places the intensification of use has high potential.

In a city where many young people have left to find work elsewhere, for example, many larger family houses might be occupied by only one or two people. If a family, student group or any other group were to move into such a house, this would greatly increase utilization. Another important question is how to make it socially and economically attractive for more people to move into available homes in currently less attractive areas. These areas could attract residents by promoting the development of efficient mobility services, efficient residences and cultural and business infrastructure.

The business opportunity arises when revitalization creates new markets that can stir investor interest and promote a general increase in local buying

power (World Bank 2016). With the right policies and public infrastructure investments, regeneration with an integrated approach can create new activity for many businesses – (re)developers; refurbishment and renovation firms; new types of property management businesses; and local cultural, gastronomical and mobility services (Floride and McLean 2017).

The likely growing consumer demand for smaller, revitalized urban centres in G7 countries justifies such investments. Many urban citizens are struggling with high rents, long commutes, poor air quality and lack of community, and seem to be looking to move to smaller towns. In 2018, as many as 60 per cent of Americans living in big cities said they preferred to live in rural areas, small towns or suburbs (Ingraham 2018; Kotkin 2012). Similar trends can be seen in France (Di Pasquale 2016) and Germany (Klug and Knipperts 2018). Well-designed revitalized urban centres are likely to be attractive for this demographic, particularly if increasing home office use facilitates more flexible choice of location. Many revitalization efforts have failed in the past, and naturally the appropriate location and approaches must suit the specific context.

Integrated urban revitalization must be led by city planners and should be supported by state or national policies, but business can be an important driving force and partner in such projects, and is arguably a crucial element in their success (Floride and McLean 2017; World Bank 2016).

Shifting demographics and urbanization are likely to create high demand for intensification through revitalization, and businesses that design and provide smarter living spaces, with better access to culture and health services, stand to benefit.

In countries with growing urbanization, such as in India or parts of China, the goal is to design smart flexible cities that provide quality of life from the outset and long-term high utilization. The IRP report, *The Weight of Cities,* provides important insights into the energy- and material-efficient design of urban living in strategic high-density nodes (IRP 2018; IRP 2020, Chapter 2.5.3).

## 2. Meet new demand and save costs in new construction

Increasing the productivity of the existing building stock will alleviate, but not eliminate, the demand for new buildings. Developers, builders and property managers will have opportunities to satisfy unmet demand for middle-income housing in G7 markets (Olick 2020) with space-efficient buildings in attractive structures that employ the more intensive use strategy. High-quality but smaller residences in multi-unit buildings can meet that demand more quickly and in more convenient locations than single-family homes.

While the trend to very small flats in high-demand cities must be critically discussed (Barhat 2015), building good-quality, space-efficient alternatives to inefficient large single family homes makes sense from an environmental, social and economic perspective. To strengthen their advantage, smart residences can

offer attractive and resource-efficient services beyond housing – easy access to transport, services and green spaces.

In emerging cities in countries with growing populations, the design of compact and integrated urban nodes can and must be pursued even more comprehensively. This effort is likely to require close cooperation between developers and city planners, and could constitute an entirely new business model that produces highly attractive results for consumers (IRP 2018).

New construction can save material and costs by using modular and prefabricated components and flexible design, an approach that may entail several enabling strategies: less material by design; fabrication yield improvements; enhanced end-of-life recovery and recycling of materials; and recovery, remanufacturing, and reuse of components.

Modular building with off-site prefabrication reduces construction waste, facilitates the use of recycled materials and encourages lean designs. Modular design can produce more flexible floor plans and enable efficient deconstruction at the end of building life for easier recovery and reuse of components. By cutting construction time in half, modular and prefabricated techniques reduce costs by about 20 per cent (McKinsey & Company *et al.* 2019).

Designing for lower production waste, higher utilization over the life cycle and better recovery at end-of-life should soon become easier. New tools are emerging to benchmark the environmental impact of components over their entire life cycle or to provide a "material passport" that tracks all materials in order to enable better reuse (Heinrich and Lang 2019).

Many planners and homeowners still believe modular buildings are of poor quality and unattractive but the image of prefabricated housing is largely a hangover from the 1960s building boom (Gerrard 2018). Today's modular buildings and the housing services they support can be highly attractive, well designed and follow sustainable principles. They need equally attractive marketing strategies supported by public information.

These strategies focused on new buildings present an even greater business case in countries with growing urbanization and the need to expand housing stock.

## **Box 6**. Modular building

**The Broad Group, China**

The Broad Group, specializing in modular construction in China, has increased production and improved logistics and installation efficiencies by using modular construction techniques. The company reports building more than 30 factory-made sustainable buildings and a 57-storey building on one site in just 19 days. According to the Broad Group, their designs result in less wasted materials and to reduce total construction costs by 40 per cent compared to traditional construction methods (EMF 2018).

Source: Ellen MacArthur Foundation 2018. The Circular Economy Opportunity for Urban and Industrial Innovation in China. https://www.ellenmacarthurfoundation.org/publications/chinareport

## **Box 7**. Public-private cooperation for more intensive use and recycled materials

**Clarion Housing Group – Merton Regeneration Project, United Kingdom**

Clarion Housing is spearheading a £1 billion housing project to provide 3,000 new homes in West London, along with 9,000 $m^2$ of retail, leisure, office, work and community space. According to the London Waste and Recycling Board, the goal of the project is to set new standards in applying circular economy principles. It is working with a start-up company, LOOP Ventures, to optimize its use of materials. It aims to repurpose or reuse fittings and materials from 1,260 local homes that are being demolished (London Waste and Recycling Board 2018).

Source: London Waste and Recycling Board website 2018. https://circularlondon.org/clarion-circular-housing/

The use of aesthetically pleasing, and sustainable materials and designs, increases the distinctiveness of buildings and their attractiveness to customers. This approach may employ material substitution (for example timber use); using less material by design; and recovery, remanufacturing, and reuse of components.

Sustainably harvested timber offers significant climate and other benefits in construction. Timber use can reduce expected building life cycle emissions in G7 countries through 2060 by about 2 per cent, by about 25 per cent in China and by about 50 per in India compared to current building materials such as concrete. Thanks to new technologies such as cross-laminated timber, wood can now be used in high-rise buildings. Interest in advanced timber framing (instead of concrete or metal structures), and wood construction more generally, is gaining more traction because of its climate benefits but also potentially because of its cost savings. Modern timber techniques can enhance productivity in construction by using prefabricated wooden building components.

Planning tools like building information modelling (a virtual process that accurately models a building project in a three-dimensional environment through collaboration with architects, engineers, contractors, suppliers and other stakeholders) can further reduce material costs and waste.

Credit: GVOJTa Herout/Shutterstock.com

## 3. Promote and meet the demand for new living services[3]

All material efficiency strategies can contribute to the construction sector's ability to meet and create demand for convenient and connected living experiences while saving material and energy costs.

To provide a living experience that goes beyond just housing, innovative business models could offer clients building maintenance, energy savings, more convenience, access to green spaces, healthcare facilities, security, shared mobility, entertainment and community services. Such service models would benefit from saving materials over the whole life cycle of buildings with the help of strategies such as extension of lifetime through insulation, renovation and repair services. Maintenance and component recovery could occur at a larger scale, at lower cost and in faster learning cycles. The possibilities of digital evaluation of utilization and maintenance needs, and possibilities for communication with residents can facilitate such models.

Such concepts can be pursued by high-end property managers as well as by more self-organized cooperative housing (Stevens-Wood 2020).

### **Box 8**. More intensive use in housing

**Vancouver cohousing complex, Canada**

In this modern cohousing complex, most residents own their homes and each unit has its own kitchen, living room, washroom and bedroom or bedrooms. But residents also share large common areas and are responsible for shared duties such as cooking communal meals and handling recycling. The organization reports that the Vancouver Cohousing members have the benefits of amenities common to a traditional home while reducing the size of their private dwelling. Residents hold monthly meetings in which decisions are made by consensus (Vancouver Cohousing 2019).

Source: Vancouver Housing website 2019. https://www.vancouvercohousing.com/

3- Based on IRP RECC 2020, Chapter 3.3.3

## **Box 9**. More intensive use, recovery and reuse and a combination of services

**Taisugar Circular Village, Republic of China**

The Taisugar Circular Village in Tainan is trialling a new circular economy housing model. The Taiwan Circular Economy Network reports that it reuses components from the existing housing stock for further urban development. Where possible, it reuses outputs from community utilities as well. Examples of reused utility outputs include stormwater circulation, a village heat-pump system, and shared solar power installations. Salvaged hardwood from rundown homes is used to build new houses and old rail tracks are recycled as fence posts. The project currently plans to create more than 300 high-quality environmental residential homes, according to the network (Taiwan Circular Economy Network 2017).

Source: Taiwan Circular Economy Network 2017. Publication Towards a Circular Taiwan: 66 Circular Stories.

## B. Business opportunities for material-efficient mobility

Effective climate action and orientation to new customer demands is a particularly urgent need in the automotive industry. Volkswagen's CEO Herbert Diess noted in January 2020 that large traditional car manufacturers may become obsolete unless they make a radical digital shift consistent with climate policy goals (Afhüppe 2020). The CEO of Bosch, the world's largest car components company, recently noted that the sector could have passed the peak of automotive production and that future success will lie in connected, electric mobility systems (Attwood 2020).

This section outlines business approaches and opportunities for material efficiency in cars. More intensive use is the priority strategy, which should be complemented by and, in many cases may facilitate, the additional benefit of other material efficiency strategies. To do so quickly enough and reap the benefits, the car mobility sector will need to reinvent concepts of ownership and value chains.

### 1. Meet consumer demand for more convenient, affordable, and flexible mobility[4]

Owning a car is already not cost effective for most vehicle owners in cities (The Economist 2016; Hägler and Kunkel 2019), given high maintenance costs and low utilization rates. The typical European car is parked 92 per cent of the time and carries on average only 1.5 people per trip (EMF 2015).

Given the strong demand for convenient sharing services, potential material savings of more intensive use, and faster electrification, the business ambition for intensification can be even higher, and the commercial potential can become more apparent.

Car-sharing and ride-pooling services are growing fast (including individual hailing which does not currently lead to efficiency gains), proving its evident appeal to consumers across the world (McKinsey Centre for Future Mobility 2020). For the moment, individual car ownership remains high. Yet it is likely to become a lot less convenient and less cost-competitive relative to

4- Based on IRP RECC 2020, Chapters 2.4.4, 3.4.2 and 3.4.4

the alternatives over the next few decades (McKinsey & Company 2019). Parking space is becoming scarce and the complexity and costs of car maintenance are growing (McKinsey@x & Company 2019). Meanwhile a growing number of businesses are working to increase the convenience and cost of pooled rides and car-sharing services through better digital hailing systems and autonomous driving technology, which is expected to become a game changer (McKinsey & Company 2019).

Shared mobility services have great potential globally. The shared mobility market already exceeds USD $60 billion in value across the three largest markets – China, Europe, and the United States – and the markets are growing (McKinsey Centre for Future Mobility 2020).

The booming demand for mobility services is not only a significant opportunity for mobility service providers, but also for those manufacturers that provide the most suitable, fuel-efficient, durable, and easy-to-maintain cars. The opportunity for businesses providing digital pooling or hailing platforms or other digital services to enhance the trip experience is large.

The rising demand for electrification in G7 countries in the European Union (Gibbs 2018) will make aiming for higher utilization models even more beneficial because higher utilization can lead to faster modernization cycles and shorten the payback period for electrification investments. Furthermore, mobility service providers can maximize the value captured per battery, a product potentially limited in availability by rare materials. They can also optimize the management of battery life and recovery (WEF and Global Battery Alliance 2019).

In the COVID-19 context, all mobility providers have seen a downturn in demand. The long-term recovery for different modes of transport remains to be seen, but many market observers see an important role for multi-modal flexible solutions (see Box 4).

### **Box 10**. Innovation in advanced ride pooling

**Uber Pool, global**

In 2014 the ride-hailing provider Uber launched Uber Pool to enable riders to save costs by sharing their trip with others heading in the same direction. As with individual ride-hailing services, customers request a ride to a destination of their choice on the app, which automatically matches the request to other people with overlapping journeys. According to Uber, the ride may take small detours and will stop a maximum of three times to pick up or drop off other riders. Business Insider reported that Uber is working on optimizing the service and guaranteeing an arrival time. According to Uber, by 2016, 20 per cent of all their rides around the world used Pool, including 30 million trips each week in China alone. While no data are available on the success of the push to improve pooling services, it shows a type of innovation that needs to be explored further (Heath 2016).

Source: Business Insider online 2016. https://www.businessinsider.com/uberpool-ride-sharing-could-be-the-future-of-uber-2016-6?r=US&IR=T

## **Box 11**. Innovation in diverse car-sharing services and automation

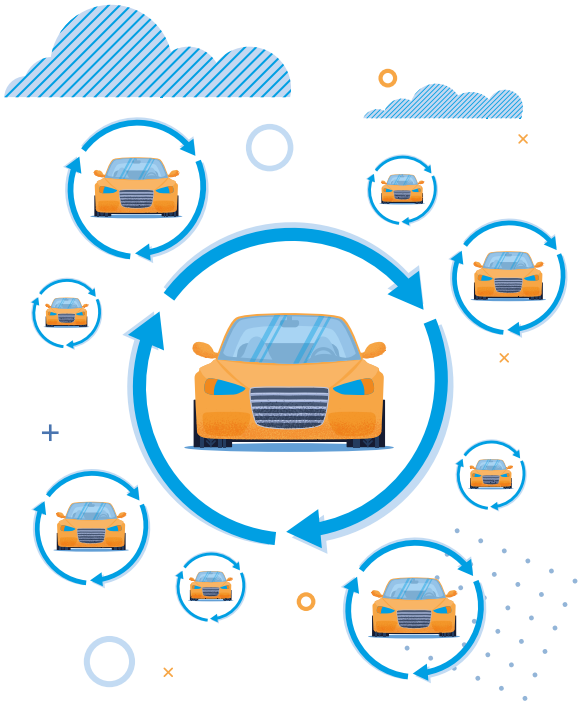
**Canoo, USA**

The startup Canoo aims to launch a new type of vehicle in 2021 that, it claims, combines the interior space of a large SUV with the carbon footprint of a compact car. According to the company, the vehicles will be human-controlled at first but can be adapted to autonomous driving technology in the future. Canoo also plans to make a vehicle suited for delivery. Canoo vehicles will be fully electric and Canoo's services will be sold through memberships (O'Kane 2019).

Source: The Verge online 2019. https://www.theverge.com/2019/3/25/18279906/new-ev-startup-canoo-will-only-sell-cars-on-a-subscription-basis


Credit: Tero Vesalainen/Shutterstock.com

## 2. Capture more value per vehicle[5]



One way to increase more intensive vehicle use is by expanding the concept of the vehicle.

For digital service providers, an important opportunity in ride-pooling is offering customers additional services such as entertainment, information or shopping offers through interactive panels in the vehicles or via the ride-hailing app (Glon 2020).

5- Based on IRP RECC 2020, Chapters 2.4.4 and 3.4.4

Utility firms may find advantages in cooperating with mobility services to use electric vehicles for energy storage (WEF and Global Battery Alliance 2019). While private vehicles could also be used this way, the centrally managed and smartly connected vehicles of mobility service providers are likely to facilitate vehicle-to-grid energy transfer.

The G7 car sector currently does not maximize the value of materials over the life cycle of cars. The 2020 IRP RECC shows that at least a 20 per cent extension of useful life is possible through better repair, with a corresponding reduction in material cycle emissions of 5-15 per cent by 2050.

Reuse or remanufacturing of components would reduce emissions by a similar amount. Improvements in end-of-life material recovery for recycling could reduce material cycle emissions by about 38-45 per cent. These improvements would require an increase from today's recovery rates of steel from 69 per cent to 95 per cent in 2050, and from 67 per cent to 82 per cent for copper.

Closed-loop recycling could increase the value of recycled materials. Using current technology, secondary steel obtained from car recycling is contaminated with copper, thereby limiting the value of the scrap and potentially limiting its use. Only about 7 per cent of the steel recovered from cars goes back into car production, with most of the recovered steel used in construction at a much lower value. Maintaining the original quality of the recovered metals allows them to be reused in cars or other high-

value applications. This closed-loop recycling largely depends on better design and processes for recovery of metals.

These strategies, in principle, would significantly reduce the material cost per kilometre driven. However, the fragmented nature of the vehicle value chain makes it difficult to implement them. The IRP RECC policy review found high recycling rates in places like Japan where producer collaboration is incentivized through extended producer responsibility policies.

Progressive organizations such as those in the Circular Cars Initiative suggest that businesses can proactively develop producer collaboration to benefit from material savings across the vehicle life cycle. Innovation can start immediately but will need clear policy support to scale up (CCI WEF 2020; Scott 2020).

Original manufacturers could keep a higher level of control over the vehicles' life cycle, for example by connecting and collaborating with other actors in the value chain, particularly fleet managers. This approach could incentivize and facilitate the design of cars for repair and recovery, as well as employ the upskilled workforce required to execute the mechanical work along the life cycle.

The opportunity and competitive pressure for businesses to pursue cooperation to capture more value from materials seems to be on the rise with two fast-emerging trends. Businesses that offer mobility as a service have incentives to maintain and remanufacture because their large fleets have high utilization that requires streamlined maintenance at scale and their digital capabilities enable them to track vehicles to their end of life. In addition, advancements in digital technology will allow for easier tracking of materials, increasingly automated disassembly, and distributed component repair.

## **Box 12**. Innovation in remanufacturing and recycling

**Renault, France**

Renault says it focuses on using secondary materials in its cars, and on producing easy-to-repair car designs. In 2017, Renault reported that it was already generating €0.5 billion revenue per year from recycling and remanufacturing operations (Renault 2017).

Source: https://en.media.groupe.renault.com/actualites/circular-economy-partnership-deepens-between-groupe-renault-and-the-ellen-macarthur-foundation-92003-989c5.html

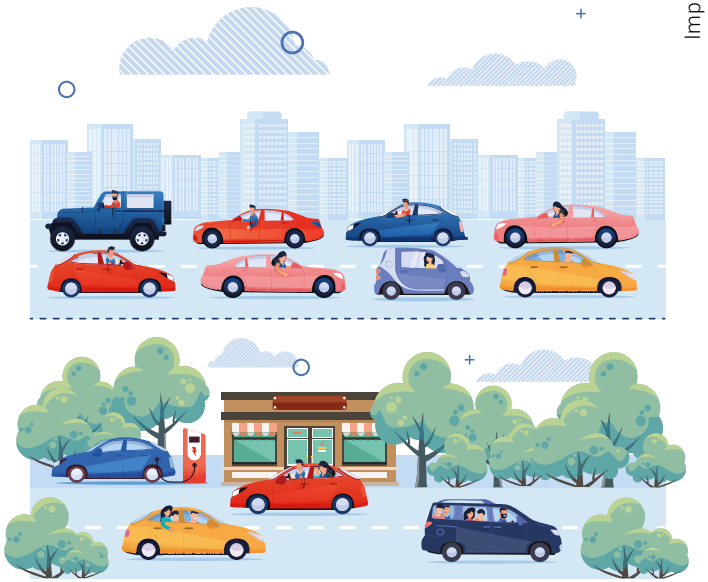
## 3. Stay relevant by meeting societal expectations of better socioeconomic performance[6]

Mobility systems based on individual car use have significant downsides for urban productivity and societal health.

Currently, congestion is causing huge economic losses around the world. The city of London, for example, estimates the annual cost of congestion will be a £9.3 billion by 2030 if current trends continue (Transport for London and Mayor of London 2018). Air pollution in cities, 92 per cent per cent of which is caused by car use, is a major factor in premature deaths (Transport for London and Mayor of London 2018; WHO 2020).The way urban environments in G7 countries are currently designed to accommodate cars is dramatically space inefficient. About 50 per cent of European inner-city land is devoted to roads and parking, but, even at rush hour, cars use only 10 per cent of urban roads. In Orlando and Los Angeles, parking lots are estimated to cover at least one-third of the land area (EMF 2015). Several Indian cities feature in the top 10 list of most regular traffic congestion (Dash 2020). Exposed roads also increase the heat-island effect, which makes urban regions warmer than surrounding rural areas (Ben-Joseph 2012).

Some cities are taking action to limit urban private car use and its consequences. San Francisco, California, and Vancouver, designated street parking spaces for free-floating car-sharing programmes in effect reducing space for private car use (IRP 2020, Chapter 3.4.2) and European cities such as Helsinki, Paris and Oslo are looking to reduce parking and road space (O'Sullivan 2020; Wijnen 2018).

Mobility providers have an important role to play in integrated multi-modal services that are particularly important to overall urban mobility performance. Ride-pooling services can cooperate with public transport to offer complementary trips and innovate to reach more peripheral areas not covered by public or shared transport services. In proactively pursuing such cooperation and offering integration, innovative businesses could have a systemic effect and create consumer awareness and demand for such integrated services – expanding not only their own role but also potentially the role of integrated models with public transport providers. This possibility does not seem unrealistic – in the case of shared bicycle and

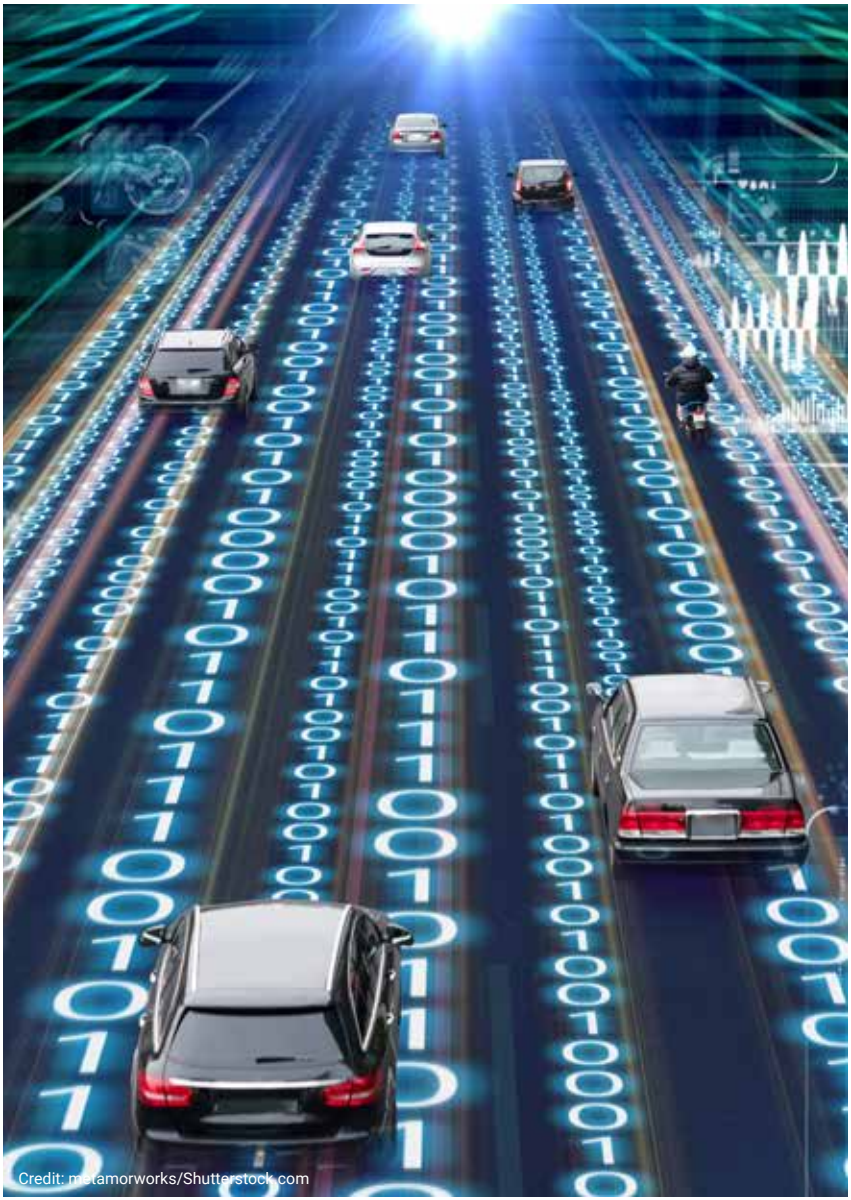


6- Based on IRP RECC 2020, Chapters 2.5.3 and 3.7.4

scooter services, innovative business has shaped new consumer behaviour (Ajao 2019).

Another important lever is data sharing. The collection and evaluation of trip and occupancy data in cooperation with cities or other public transportation planning bodies could improve travel options, and make public and private shared transportation more cost efficient, material-efficient and demand driven, hence more economically and socially beneficial.

The role of flexible transport services and integrated multi-modal platforms has seen new risks but also more importance in the context of the COVID-19 Pandemic. Implications for the design and operation of shared transport must naturally be further discussed by businesses, policymakers and users as the importance of flexible mobility services is likely to grow.


Credit: metamorworks/Shutterstock.com

## C. Next steps for business leaders

The following recommendations for implementing material efficiency strategies and the related business model changes are based on stakeholder inputs.

### 1. Anchor business vision in material efficiency and climate science

Some businesses have already begun to integrate emission reductions in their business vision and strategy. Businesses in the housing and mobility sector, and material-intensive sectors more generally, need to integrate mid- and long-term climate and resource risk assessments into their business strategies. Beyond risks, the business vision should include how a decoupled business model would look and how material efficiency strategies can play a major role.

### 2. Invest in innovative pilots

Material efficiency strategies are essential for modern businesses. The trend towards business models providing functionality instead of product sales will increase resilience in a world of climate change and rising or more volatile resource prices. Of course, many of these changes require fundamentally new thinking to overcome significant complexity. This challenge should not slow business action until the perfect models are found. It should rather encourage businesses to test new approaches in pilot projects, or potentially create or join pre-competitive coalitions with other organizations or public innovation programmes, and to establish regular exchange with consumers and citizens. Digital tools, such as smart phone applications or interfaces in appliances, as well as personal communication will play a role in evaluating changing consumer experiences.

## 3. Demand and support policy development

The IRP report identifies a big gap in policy supporting material efficiency strategies. But only with the right policies to set fair market conditions, can businesses fully benefit from the resource savings, new service-oriented business models and new (regenerated) urban markets. Frontrunners in innovative business models and technologies can secure an important competitive advantage from better policies that take into account the real value of natural resources.

Business leaders must use their voices to advocate for material efficiency policies and offer their expertise to inform the development of new policies.

One way for business leaders to do so is to use their weight in industry associations to drive progressive positions on resource policies. Business can also join or co-create purpose-specific coalitions such as the Energy Transitions Commission or the Word Economic Forum's Circular Cars Initiative (CCI WEF 2020; ETC 2020).

Business voices can provide important political space for leaders in governments to drive system-wide material efficiency policies at home and internationally, which in turn can provide a competitive advantage to innovative firms. A much-cited example of a strong business role in resource-related policymaking is the 1980s push by major chemical companies for a strict international agreement on ozone depleting substances, which arguably enabled the Montreal protocol in 1987 (Maxwell and Briscoe 1997).

Particularly in city contexts, business leaders can also pursue direct private-public partnerships, for example in the matter of city revitalization, neighbourhood development or integrated public-private mobility solutions. Data sharing is an important tool that business can provide to policymakers to design beneficial regulation and investments.

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International Resource Panel

**Resource Efficiency and Climate Change:**
Material Efficiency Strategies for a Low-Carbon Future

Implications for Business Leaders in Housing and Mobility

The International Resource Panel (IRP) was established to provide independent, coherent and authoritative scientific assessments on the use of natural resources and their environmental impacts over the full life cycle. The Panel aims to contribute to a better understanding of how to decouple economic growth from environmental degradation while enhancing well-being.

The Secretariat is hosted by the United Nations Environment Programme. Since 2017, the IRP has published twenty-eight assessments. These assessments demonstrate the opportunities for governments, businesses and wider society to work together to create and implement policies that ultimately lead to sustainable resource management, including through better planning, technological innovation and strategic incentives and investments.

This "Implications for Business Leaders" document accompanies a report that was developed by the IRP in response to a request by leaders of the Group of 7 nations in the context of efforts to promote resource efficiency as a core element of sustainable development. It conducts a rigorous assessment of the contribution of material efficiency to GHG abatement strategies. More concretely, it assesses the reduction potential of GHG emissions from material efficiency strategies applied in residential buildings and light duty vehicles, and reviews policies that address these strategies.

According to the Panel, GHG emissions from residential buildings in the G7 and China could be reduced by at least 80% in 2050 through more intensive use of homes, design with less materials, improved recycling of construction materials, and other strategies.

Significant reductions of GHG emissions could also be achieved in the production, use and disposal of cars. IRP modelling shows that GHG emissions from passenger cars in 2050 could be reduced by up to 70% in G7 countries and 60% in China and India through ride-sharing, car-sharing, and a shift towards trip-appropriate smaller cars, among others.

Increasing material efficiency is a key opportunity for moving towards the 1.5° C target in the Paris Agreement. Materials are vital to modern society, but their production is an important source of greenhouse gases. Emissions from material production are now comparable to those from agriculture, forestry, and land use change combined, yet they have received much less attention from the climate policy community. As shown by IRP estimates, it is time to look beyond energy efficiency to reduce global carbon footprint.

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