CHAPTER 2

Commodity Demand: Drivers, Outlook, and Implications

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Commodity consumption has surged over the past half-century. Metal commodities led the way, rising four-fold between 1970-2019, followed by a three-fold increase in energy and agricultural commodities. Key drivers of this growth have been income and population growth, with demand for metals the most responsive to rising income. Technological innovations have heavily influenced the commodity intensity of output by boosting efficiency in the consumption and production of commodities. Government policies, through taxes, subsidies, and regulation, have also had strong effects. These factors, along with changes in relative prices reflecting the relative scarcity of resources, affect the composition of demand as well as the total. Over the decades ahead, the energy transition is expected to be a primary driver of substitution among commodity groups. The switch to low carbon sources of energy is anticipated to reduce consumption of hydrocarbons but increase consumption of the metals used to produce clean energy, such as copper.

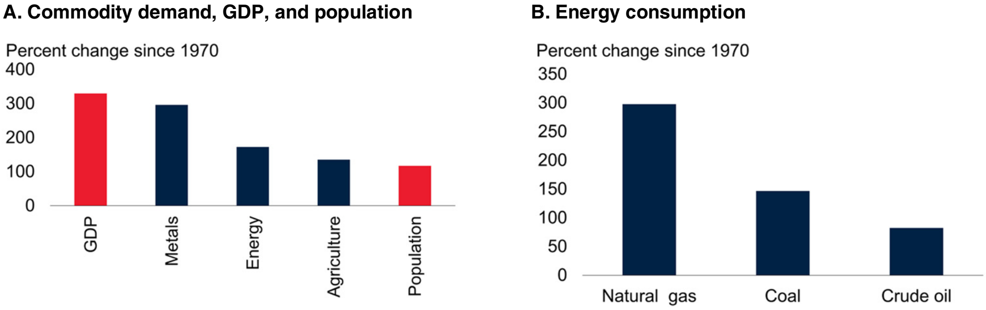
Introduction

Global consumption of natural resource-based commodities has seen a substantial increase over the past half-century, but at significantly varying speeds across the major commodity groups. Consumption of base metals rose more than four-fold from 23 million metric tons (MMT) in 1970 to 107 MMT in 2019—a growth similar to that of global GDP (figure 2.1). Consumption of energy materials nearly tripled over the same period, from just over 200 exajoules to 580 exajoules, as did consumption of food commodities. Aluminum experienced the fastest growth of the base metals, rising more than six-fold, due to its increasing use as a substitute for other metals, particularly in the transport industry (Chen and Graedel 2012). Among energy commodities, natural gas consumption rose four-fold, thanks to its clean-burning properties relative to crude oil and coal. Among food commodities, the sharpest increases were for inputs to processed consumer products, animal feed, and biofuels, with edible oils rising eight-fold and corn four-fold. Consumption of other grains doubled, broadly in line with the increase in world population over the past 50 years.

The speed of these increases has varied over time. After rapid growth in the 1960s and 1970s, commodity demand slowed sharply in the 1980s-90s, before picking up again in the 2000s. The post-2000 demand surge was driven by strong growth in emerging market and developing economies (EMDEs), most notably China. China's exceptionally rapid economic growth, focused on commodity-intensive manufacturing and investment, raised its share of world metal consumption to 50 percent in 2019, up from 10 percent two decades earlier (figure 2.2; World Bank 2018a, 2018b). While commodity consumption also rose strongly in other EMDEs, their share of global consumption remained relatively constant.

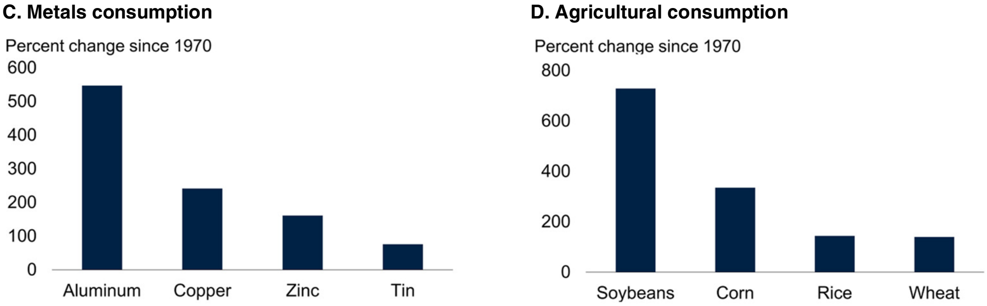
FIGURE 2.1 Changes in commodity demand

Commodity demand has surged over the past fifty years. Demand for metals has grown particularly rapidly with more than a four-fold increase, similar to GDP growth. Energy and agricultural demand tripled, slightly faster than the increase in global population. Among individual commodities, natural gas has seen the fastest growth of the energy commodities, aluminum has seen the fastest growth among metals, while soybeans have seen the fastest growth among agricultural commodities.



A. Commodity demand, GDP, and population

B. Energy consumption



C. Metals consumption

D. Agricultural consumption

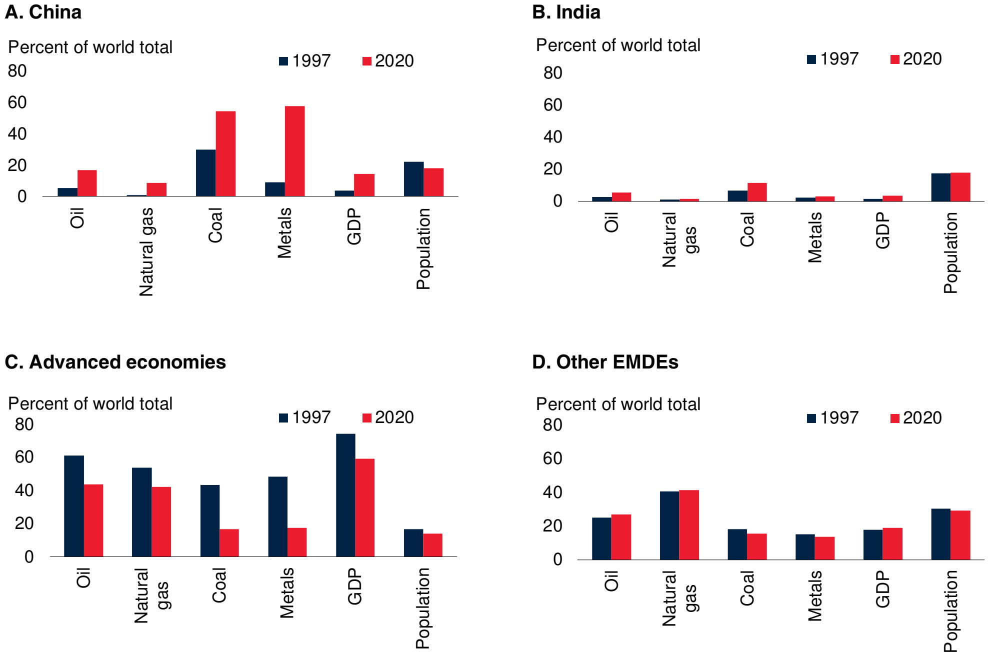
Sources: BP Statistical Review; U.S. Department of Agriculture; World Bureau of Metals Statistics; World Bank.
Note: Change in commodity demand, GDP, and population between 1970 and 2020.

Understanding the causes of variations in the long-term growth in commodity demand is of critical importance for the economic prospects of EMDE commodity exporters. Knowing how key drivers—such as population growth, income growth, technology, or policies—shape long-term trends is a first step in making projections of future commodity demand growth. For commodity exporters, this is a crucial input in projecting future fiscal and export revenue. For commodity importers, this can inform estimates of future resource needs, which in turn can help safeguard energy and food security. Long-term dependence on resource-based sectors can leave a country vulnerable to external shocks to the terms of trade. The scale and nature of resource extraction also have strong environmental implications.

The current outlook for commodity demand has an unusually large and unpredictable component. Transformative change is on the horizon because of the energy transition. Clean energy technology, and related industrial innovation, are advancing at a rapid rate, including cost reductions in generating electricity from renewable resources, battery storage, and electric vehicles. Policies are strongly encouraging these changes, with

FIGURE 2.2 Changing shares of consumption of industrial commodities

Between 1997 and 2017, China's share of global GDP tripled, while its share of population shrank 10 percent. At the same time, its share of oil consumption doubled, and its share of metals consumption rose five-fold to around 50 percent. In contrast, while India's share of global GDP doubled, its share of consumption of all major industrial commodities increased more slowly. The increase in China's share of global commodity consumption came primarily from advanced economies, with a particularly steep fall in their share of metal consumption.



A. China

B. India

C. Advanced economies

D. Other EMDEs

Sources: BP Statistical Review; U.S. Department of Agriculture; World Bank; World Bureau of Metals Statistics.

A.-D. Sample of countries included in this figure collectively accounted for 97 percent of global GDP and 83 percent of global population in 2017. Due to data limitations fewer countries are available for metals demand.

B. AEs stands for advanced economies and contains 29 countries for all categories except metals, which contains 27 countries.

D. EMDEs stands for emerging market and developing economies and contains 33 countries for all categories except metals, which contains 29 countries. Aggregates exclude China and India.

governments and international institutions announcing measures to mitigate the impact of climate change as well as other environmental issues related to the consumption and production of commodities.

Against this backdrop of accelerated innovation, and the likelihood of fundamental changes in commodity use, this chapter addresses the following questions:

- What have been the historical determinants of commodity demand?
- How does commodity demand evolve quantitatively as economies develop?
- What are the prospects for global commodity demand, and what are the implications for policy makers?

Contribution to the literature. This chapter presents estimates of income elasticities of demand for the energy, metals, and food commodity groups. It builds on the research in Baffes, Kabundi, and Nagle (2022), which estimates income elasticities of demand for the individual commodities within each of these sectors. The results reported in this chapter control for the presence of long-term substitutions between commodity groups, in both production and consumption. The use of a common framework facilitates a comparison of income elasticities across commodity groups. Previous studies have typically been more narrowly focused on a single commodity group, with much of the literature focusing on energy.

The chapter uses a methodology that enables the estimation of income-varying elasticities of demand, in contrast to most previous studies which for a given commodity provide estimates of linear income elasticities, uniform across all levels of per-capita income. Calculating non-linear elasticities of demand enables an analysis of how commodity demand changes at different stages of economic development.

Main findings. This chapter has three main findings. First, population and income growth are the two primary drivers of aggregate commodity demand in the long run. Whereas income is a key driver of growth for metals and energy, it is less important for food commodities, which tend to be driven chiefly by population growth. Other factors, including relative prices, technology, substitutions from one commodity group to another, and government policies, are also important drivers of demand growth. These factors can lead to changes in the intensity of commodity demand for a given level of per capita income, as well as changes in the relative importance of individual commodities.

Second, per-capita income elasticities of demand vary significantly between commodity groups. Base metals have the highest income elasticity of demand, followed by energy. The lowest income elasticity is for food. Growth in metals consumption over the past fifty years has closely tracked growth in income (reflecting growth in both population and GDP per capita), whereas growth in food consumption has more closely followed population growth, particularly for grains. In addition, income elasticities vary with per capita income levels. At low levels of income, elasticities of demand for commodities are high (in some cases well above unity). As per capita income levels rise, the marginal income elasticities fall. At high levels, the marginal elasticities may go to zero, or even negative, reflecting shifts in consumption patterns toward goods with high value-added content, and toward services, as per capita incomes rise. This decline was larger for metals and energy than for agriculture, but since the starting elasticity for metal was high, it remains the most income elastic component of commodity demand.

Third, overall commodity demand is likely to continue to increase in the years ahead, but at a slower rate than over the past two decades. This is due to slower anticipated population and income growth, as well economic changes, such as China's shift toward a more service- and consumer-based economy. Demand for individual commodities could see transformative substitutions because of innovations and policy-driven initiatives to mitigate climate change. The energy transition is likely to feature a wave of disruptive change that will cause large, permanent changes in the demand for commodities. A shift to low-carbon sources of energy is expected to raise demand for metals used for clean energy (such as copper), and much reduce the consumption of fossil fuels.

The rest of this chapter is structured as follows. The next section presents a historical description of trends in the key drivers of commodity demand—population, income levels, and commodity intensity (i.e., changes in the efficiency of commodity consumption and production due to innovation). Section 3 presents empirical estimates of income elasticities of demand for the three sectors: metals, energy, and food. Section 4 considers the prospects for future commodity demand growth, based on expected income and population trends. Section 5 offers some policy implications. Boxes investigate the relationship between urbanization and commodity demand, and some notable historical examples of commodity substitution.

Classifying the determinants of commodity demand

Population and income growth, and technological progress, have been fundamental drivers of demand for commodities. Innovations in production have often caused large-scale substitutions from one commodity to another. They have also led to changes in the commodity intensity of output—i.e., commodity consumption per unit of GDP. Box 2.2 provides a history of some key examples of this kind since the industrial revolution.

Commodity demand, C_t, can be expressed as the following identity:

$$C_t = (pop_t) * \left(\frac{Y_t}{pop_t}\right) * \left(\frac{C_t}{Y_t}\right), \tag{1}$$

where pop_t and Y_t denote population and income at time t. The three factors included in the parentheses—population, per capita income, and commodity intensity—are interrelated. For example, as countries get wealthier, demand tends to shift from goods that are intensive in commodities toward products with a higher component of value added, notably services. With economic development, GDP per capita increases, and output becomes less commodity-intensive over time. The three subsections that follow describe historical trends in the way each of these factors has affected commodity demand.

Population

Demographics have been a key driver of commodity demand over the past 50 years. Commodity consumption at the global level is directly linked to the size of the global population. Basic material needs, such as food, clothing, shelter, and heat are an important part of this linkage, as well as other material wants. Agricultural commodities provide food, clothing, and other raw materials; metals and minerals are essential components of shelter; and energy commodities fuel transport, heating, and lighting. In addition to material needs, people have material wants for goods and services for which resource-based commodities are essential inputs (e.g., beverage crops such as coffee, precious metals for jewelry, and energy use in leisure activities such as flying). If each additional person has a similar consumption pattern to the existing population, an increase in population leads to a proportional increase in commodity demand, as per the identity in equation (1).

Over the past 50 years, the global population has more than doubled, from 3.7 billion people in 1970 to 7.8 billion people in 2020. The rate of population growth in percentage terms has gradually slowed, from almost 2 percent per year in the 1970s, to just over 1 percent in the 2010s (the absolute number of population increase has remained stable, at almost 80 million people per year).

However, demand for commodities has not grown at the same rate as population. One reason is that per capita commodity demand varies significantly between countries. For example, whereas per capita energy consumption at the global level averaged 75 gigajoules (GJ) in 2019, in advanced economies (AEs) it averaged 173 GJ, but only 55 GJ in EMDEs. For metals, differences between AEs and EMDEs were less striking, largely due to China's high per capita metal consumption. Across individual countries, differences are starker. For example, per capita energy and metal consumption in 2019 were approximately 10 times higher in the United States than in India (figure 2.3). Differences in agricultural consumption are less marked, with U.S. consumption roughly two-and-a-half times higher than in India.

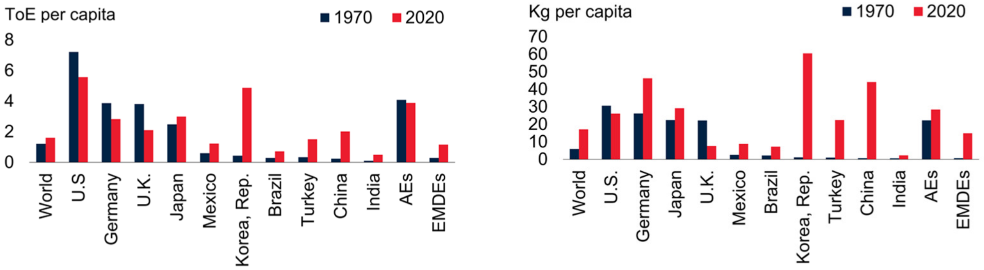
An associated reason for the change in global per capita consumption in commodities over the past 50 years is that population growth has been uneven. Most of the increase in population has occurred in countries with per capita commodity consumption levels below the global average. Since 1970, EMDEs have accounted for 77 percent of the growth, with 14 percent from LICs and less than 10 percent from AEs. As a result of the declining fraction of rich countries in global population, the increase in commodity demand due to population growth has been less than global demographics might imply.

This point can be illustrated with a simple, if counterfactual, numerical scenario. Suppose that per capita commodity consumption for each country remains at the 1970 level. Consumption in each country then grows at a rate equal to its specific population growth rate. Under this stylized scenario, while world population more than doubled between 1970 and 2019, global energy demand would have increased by just 55 percent, and metal demand by 44 percent. The increase in commodity consumption due to population growth is smaller than the actual increase in population growth because much of it happened in countries with below-average per capita commodity consumption. In contrast, the increase in food consumption under the scenario is 84 percent, far closer to population growth, because of the relatively small difference in per capita food consumption between AEs and EMDEs.

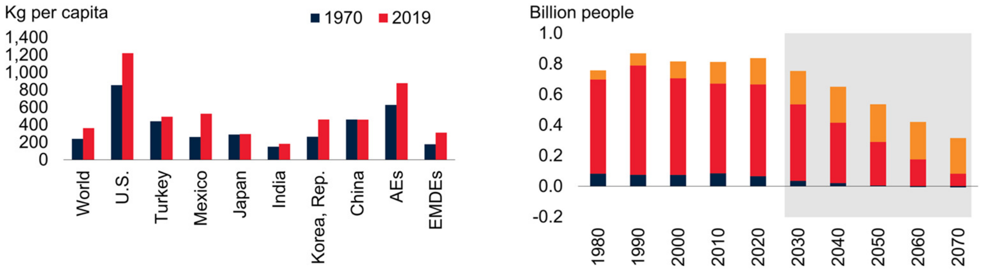
This numerical exercise assumes, counterfactually, that commodity demand per capita remains constant. In fact, it has increased significantly over the past 50 years in many countries. This change does not invalidate the relevance of the scenario as an illustration of the important effect of differences across countries on the growth of global demand. However, it does indicate that the two factors other than population in equation (1)—

FIGURE 2.3 Population and commodity demand

Global per capita consumption of commodities has risen over the past 50 years, driven by an increase among EMDEs. Among advanced economies, per capita commodity consumption has fallen slightly, although consumption levels are still much higher. There has been less change in agricultural consumption, and disparities in consumption levels between advanced and emerging economies is smaller. While global population has increased by around 80 million people per year over the past half-century, growth is expected to slow over the next 50 years and will be increasingly driven by low-income countries.


A. Energy consumption per capita

B. Metal consumption per capita


C. Agricultural consumption per capita

D. Global population growth forecasts, by income group

Sources: BP Statistical Review; World Bank; World Bureau of Metals Statistics.
Notes: Energy includes oil, natural gas and coal. Metals includes aluminum, copper, and zinc.
A.-C. AEs stands for advanced economies, EMDEs stands for emerging market and developing economies.

per capita income and the intensity of commodity demand—must also have had a sizable impact. These factors are investigated in the next two parts of this section.

Per capita income

The relationship between economic development and commodity demand is, on the surface, straightforward: as people's incomes rise, their material demands increase.[1] For example, in the case of transport, as people get wealthier, they shift from predominantly muscle-powered transport such as walking, cycling, or animal transport, toward

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[1] Early studies on the relationship between income and commodity consumption such as the declining terms of trade hypothesis implicitly assumed that the relationship was stable over time, and invariant across commodities and countries (Prebisch 1950; Singer 1950).

motorized forms of travel, such as cars and trains. In addition, they travel more for pleasure, notably by sea and air (Parikh and Shukla 1995). This leads to greater material consumption, including metals (for making vehicles), and energy commodities (especially crude oil in the past half-century). Similarly, as incomes rise people use more space, including larger houses, which is associated with the use of more resources, including construction material, as well as energy to heat, cool, and light the larger space, and to fuel transportation for commuting and shopping, etc., in less densely built locations (Brounen, Kok, and Quigley 2012; Liu et al. 2003).

The relationship between per capita income growth and commodity demand is non-linear.[2] The relationship has been estimated to follow an inverse-U or an S shape, with demand for commodities initially growing rapidly at low levels of income, and then plateauing or even declining at higher income levels. This is due to four factors: the evolution of an economy's production and consumption as it develops, differences in sectoral growth patterns across countries, urbanization, and improvements in technology and efficiency. The rest of this sub-section explores these factors.

Rising per capita income, plateauing commodity demand

Over the past half-century, per capita GDP at the global level rose from just under $5,000 in 1970 to $11,000 in 2019 (in constant-value, 2019, USD). In EMDEs per capita GDP quadrupled from $1,200 to nearly $5,000, an average annual growth rate of 3 percent. Per capita GDP growth was particularly rapid in China, where it increased from less than $300 in 1970 to more than $10,000 in 2020, an average annual growth rate of 7.7 percent. Because the majority of rapid economic growth occurred in countries with low levels of per capita income, it led to an overall increase in commodity demand of similar magnitude.

However, per capita consumption of most commodities shows a profile that first rises, as per capita income increases from a low level, and later plateaus, as income grows above a certain range (figure 2.4).[3] There is even some evidence of declining per capita consumption at higher levels of income for some commodities. The precise form of the

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[2] The non-linear nature of the commodity consumption–income relationship throughout the development process has led to a strand of literature that comes under various names: the material or environmental Kuznets curve; S-shaped curve; inverted U-shaped curve; dematerialization hypothesis; the intensity of material use hypothesis; and plateauing hypothesis (Bogmans et al. 2020; Clark 1940; Herman, Ardekani, and Ausubel 1990; Kuznets 1971; Tilton 1990; Cleveland and Ruth 1998; Radetzki et al. 2008).

[3] The empirical literature on the commodity consumption-income relationship is rich, with a split between studies focused on individual commodities, and a smaller literature on group aggregates, primarily energy. At a primary commodity level, Lahoni and Tilton (1993), Stuermer (2017), and Fernandez (2018a, 2018b), among others, examined individual base metals; Jaunky (2012) looked at aluminum; Guzmán, Nashiyama and Tilton (2005) and Bailliu et al. (2019) studied copper; and Wårrel (2014) and Crompton (2015) covered steel. Other studies looked at individual energy commodities, including oil (Gately and Huntington 2002; Hamilton 2009), natural gas (Krichene 2002; Erdogdu 2010), and coal (Chan and Lee 1997; Shealy and Dorian 2010). Demand for final products has also been studied extensively—see Kamerschen and Porter (2004) for electricity; Drollas (1984), Gately and Streifel (1997), and Dahl (2012) and for gasoline and diesel. At the aggregate level, several studies look at the demand for energy (Burke and Csereklyei 2016; Csereklyei and Stern 2015; Dahl and Roman 2004; Jakob, Haller, and Marschinski 2012; Bogmans et al. 2020), while Baffes, Kabundi, and Nagle (2021) cover both individual and group aggregates for energy and metals.

relationship between commodity demand and income can vary substantially among countries. For example, China's per capita consumption of most metals is comparable to or higher than that of the AEs, despite a much lower level of income.

The plateauing in commodity demand can be interpreted as a decrease in the commodity intensity of GDP. As economies get wealthier, the quantities of commodities used in the production of an additional unit of GDP decreases. Indeed, over the past 50 years, the commodity intensity of demand at the global level has, in general, decreased for most commodities, driven by the increasing importance of the service sector in the global economy and reduced infrastructure requirements and efficiency improvements (figure 2.5; Evans and Lewis 2005; Fernandez 2018a). However, there have been some notable differences: the intensity of energy and food in GDP has declined steadily over this period, whereas that of metal demand fell until about 2000, then began rising, before plateauing in recent years.

These patterns reflect major differences between countries. While energy intensity has decreased at the global level, this has been chiefly because of reductions among advanced economies. Energy intensities have risen among most EMDEs as they have industrialized. Two notable exceptions are China and Poland, which had among the highest energy intensities in the world in 1970.[4] For metals, the sharp reversal of the global downtrend in the intensity of demand in 1995 was driven entirely by China's industrialization. Excluding China, the intensity declined at a similar rate to energy. For agriculture, intensity fell at the fastest rate of all commodity groups and fell in most countries, consistent with the low income elasticity of demand for agricultural products.

Commodity intensity of demand

At a given level of per capita GDP, four factors may influence an economy's commodity intensity of demand: the degree of industrialization, urbanization, technology, and government policies. This subsection examines each of these.

Industrialization

Historically, as economies develop, their consumption patterns change. For economies already at high income levels, incremental growth in income typically leads increased consumption of services, rather than goods, and services are much less commodity intensive. In addition, as economies mature infrastructure needs are increasingly fulfilled, reducing their need for construction materials (Tilton 1990; Radetzki et al. 2008; Stuermer 2017). A similar pattern occurs in terms of production: as economies move from predominantly agricultural economies toward manufacturing, their

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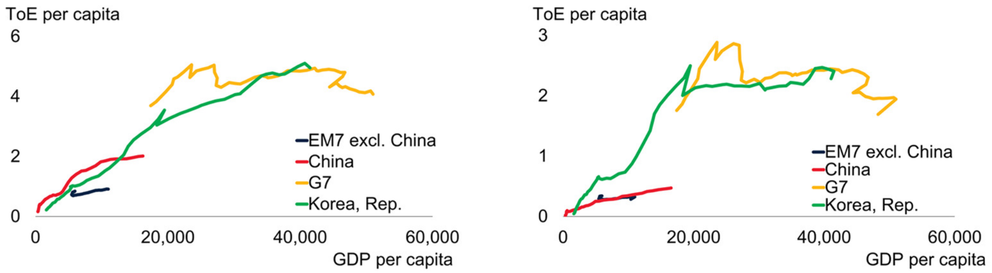
[4] Countries that industrialized under central planning tend to exhibit high energy intensity because of inefficient resource allocation (Dienes, Dobozi, and Radetzki 1994, Urge-Vorsatz, Miladinovab and Paizs 2006, Ruhl et al. 2012). Following the collapse of the Soviet Union, and coinciding with rapid per capita income growth, the energy intensity of demand in these countries fell steadily, although it remains elevated. China has a similar profile, with its energy intensity (measured as energy use relative to GDP) extremely high in the 1980s and steadily declining subsequently as its per capita incomes rose.

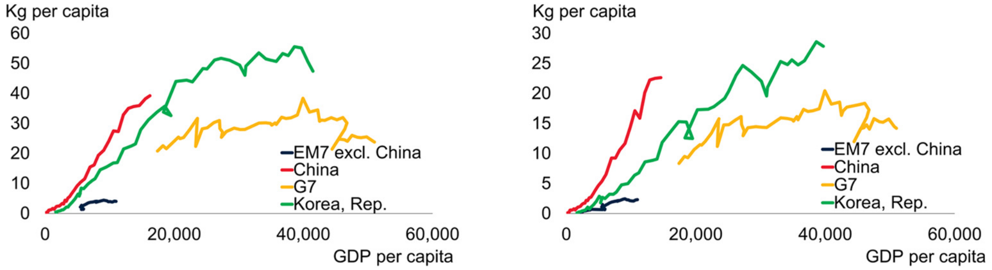
FIGURE 2.4 Income and commodity demand

The relationship between income per capita and commodity consumption per capita shows signs of plateauing for most commodities as income rises. While the relationship for energy is similar across countries, there is more divergence among countries for metals. China stands out as having higher metals consumption per capita at lower levels of income than other countries, particularly in the case of aluminum. For agriculture, there is less of a strong relationship with income, with signs that demand plateaus at low levels of income.



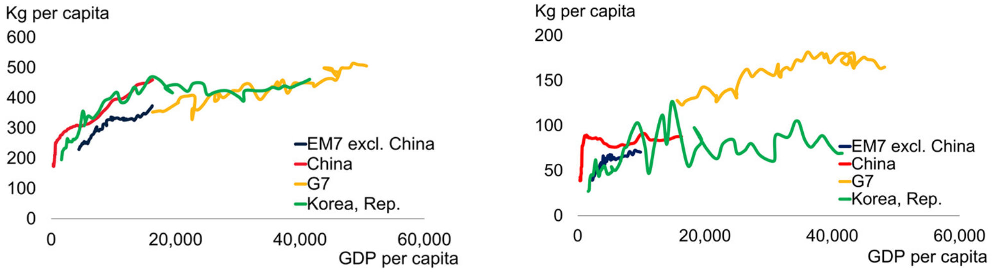
A. Energy

B. Oil



C. Base metals

D. Aluminum



E. Agriculture

F. Wheat

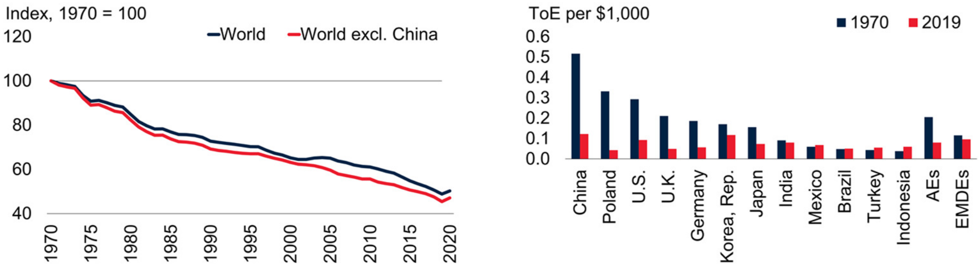
Sources: BP Statistical Review; U.S. Department of Agriculture; World Bank; World Bureau of Metal Statistics.

Note: GDP per capita in constant 2010 U.S. dollars. Lines show the evolution of income and commodity consumption per capita over the period 1965-2019. Each data point represents one country or group for one year. “EM7 excl. China” includes Brazil, India, Indonesia, Mexico, Russia, and Turkey.

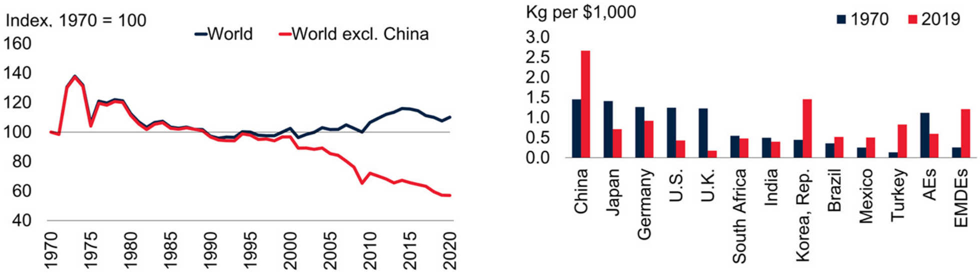
A.B. ToE stands for tonnes of oil equivalent.

FIGURE 2.5 Intensity of commodity demand

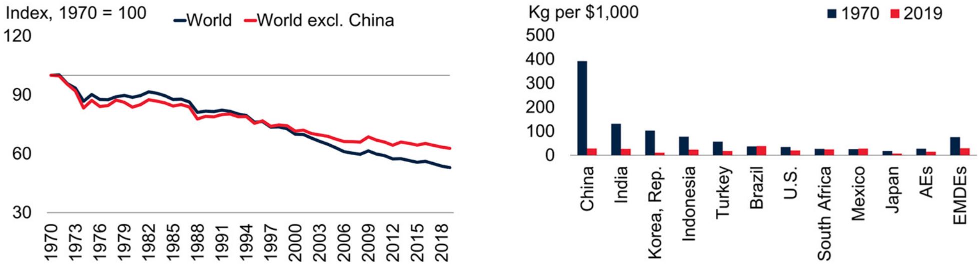
Over the past 50 years the intensity of commodity demand—the amount of commodities consumed per unit of GDP—has generally declined for energy and agriculture, but declined and then rose for metals. The global aggregates are driven by diverging trends at the country level, with intensities of demand typically falling in advanced economies and rising for EMDEs. An exception is agriculture, where the sharpest changes were for EMDEs.


A. Energy intensity of demand

B. Energy intensity of demand, select countries


C. Metal intensity of demand

D. Metal intensity of demand, select countries


E. Agricultural intensity of demand

F. Agricultural intensity of demand, select countries

Sources: BP Statistical Review; U.S. Department of Agriculture; World Bank; World Bureau of Metals Statistics.

Note: Intensity of demand is calculated as the amount of energy, metal, or agricultural commodities used per unit of GDP. Energy includes crude oil, natural gas and coal. Metals includes aluminum, copper, lead, nickel, tin, and zinc.

B. ToE stands for tonnes of oil equivalent.

commodity demand rapidly increases as manufacturing is more resource-intensive than agriculture, particularly for metals. At a later stage of development, economic growth tends to be increasingly accounted for by the service sector.

These trends are evident in the global data. For example, the share of the service sector in world GDP rose from around 50 percent in 1970 to 64 percent in 2019. Natural endowments can make a difference to the commodity composition of GDP. For example, Australia, Canada, and Chile are resource-rich countries with relatively large extractive industries. In contrast, the large East Asian economies have based their industrial development on manufacturing sectors.

Urbanization

The degree of urbanization has been linked to commodity demand growth (Yu 2011, Jacks and Stuermer 2018). The share of the global population living in urban areas has risen rapidly over the past 50 years, alongside a major increase in commodity consumption. Urban areas have large resource needs, for their construction and maintenance, for materials for their factories, and for everyday needs of their households. However, the effect of migration from the countryside to a city on commodity demand depends on the relative efficiency of resource use in the two areas (World Bank 2010). Furthermore, economic growth is also a key driver of urbanization, such that the relationship between urbanization and commodity demand is complex. Research on this relationship is surveyed in Box 2.1.

Technology

Technological innovation is a key determinant of commodity demand. Disruptive innovation is a change that renders existing products or industries obsolete. It may involve the introduction of an entirely new product (e.g., the mobile phone), new methods of production (e.g., robots), or new techniques for marketing (e.g., internet shopping). Technological developments can also introduce significant efficiency gains both on the consumption and production side. In turn, this can encourage large-scale commodity substitution (Baffes, Kabundi, and Nagle 2022; Tilton and Guzmán 2016). For example, improvements in global energy efficiency, such as increased thermal efficiency of fossil fuel power plants and improved fuel economy of internal combustion engines, have been estimated to have lowered global energy consumption by around 1.2 percent per year between 1971 and 2017 (Bogmans et al. 2020). Similarly, innovations in production processes can sharply reduce resource use and production costs in manufacturing processes (e.g., 3D printing; Campbell et al. 2011).

Oil is an important case in point. The first commercial discoveries in the mid-1800s led to rapid advances in drilling technology, and a steep drop in the relative price of oil. Along with the simultaneous invention of the internal combustion engine, this resulted in the gradual displacement of coal in transport (from steam engines to gasoline and diesel). More recent innovations in oil production (in part due to a rise in oil prices after 1973), led to the exploitation of offshore oil, oil sands, and more recently shale oil.

BOX 2.1 Urbanization and commodity demand

The past 50 years have seen a rapid increase in urbanization rates in EMDEs and this is set to continue over the next 30 years. Urbanization can have a major impact on the composition of commodity demand given the size of cities and their concentration of people and economic activity. Empirical evidence shows that, even after controlling for income and population, an increase in the share of the population living in urban areas has generally been associated with higher energy consumption. However, high density cities have lower per capita energy consumption than less densely populated cities. Adoption of well-designed policies would allow increased urbanization to proceed along with a reduction in commodity use. These would include policies to encourage public transit, greater population intensity, improved insulation of buildings, and investment in modern energy-saving equipment.

Introduction

Over the past 50 years the share of the world's population living in urban areas has risen from 37 percent to 56 percent, an increase of three billion people (figure B2.1.1 ; United Nations 2019; World Bank 2021a). The sharpest increase came from emerging market and developing economies (EMDEs), where the share of the urban population nearly doubled from 28 percent to 54 percent. The largest increase came from China, where the share of the urban population jumped from 17 percent to 61 percent between 1970 and 2020. Urbanization in advanced economies mainly took place earlier in the 20th century. Urban areas cover less than 3 percent of the world's land area, but account for roughly two-thirds of global energy consumption (UN Habitat 2020).

The shift from rural to urban areas is set to continue, with the share of the urban population at the global level expected to reach 68 percent by 2050, before plateauing thereafter (United Nations 2019). Most of this growth is expected to continue to occur in EMDEs, and in low-income countries (LICs), especially in South Asia and Sub-Saharan Africa (SSA).

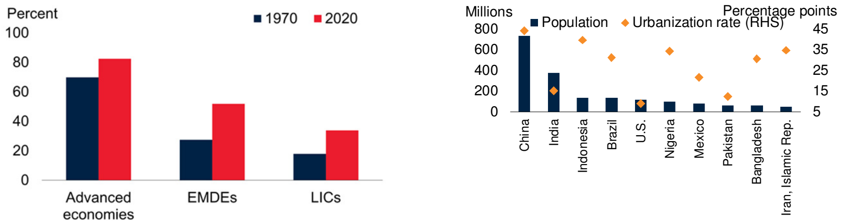
The increase in the share of the urban population has occurred alongside a rising trend in per capita commodity demand. While population and income growth are primary drivers of commodity demand, urbanization also has the potential to have a major impact, especially on the composition of demand, as city dwellers have different propensities to consume resources than rural dwellers (Baffes, Kabundi, and Nagle 2021).

Urbanization can affect commodity demand through several channels, but the impacts vary depending on the nature of urbanization (World Bank 2010, 2021b). Density of urban areas varies, ranging from high-density mega cities, to smaller cities, to low-density urban sprawls that result in dependency on automobiles and prohibit walking (Benfield, Raimi, and Chen 1999; Burchell et

BOX 2.1 Urbanization and commodity demand *(continued)*

FIGURE B2.1.1 Urban population trends

Urban populations have risen rapidly in EMDEs and LICs over the past half-century. China saw the largest increase in its urban population, followed by India. Over the next 30 years, the largest increases in urbanization are expected to occur in Sub-Saharan Africa and South Asia.

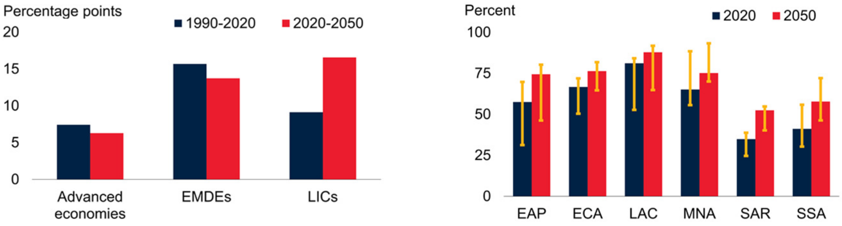


A. Urban population share

B. Change in urban population and urbanization rate, 1970-2020, select countries

C. Urban population share forecasts

D. Urban population share forecasts, by region



Sources: United Nations Population Division; World Bank.

Note: EMDE = emerging market and developing economies; LIC = low-income countries. EAP = East Asia and Pacific, ECA = Europe and Central Asia, LAC = Latin America and the Caribbean, MNA = Middle East and North Africa; SAR = South Asia, SSA = Sub-Saharan Africa. Orange whiskers indicate minimum and maximum range.

A.-D. Charts show data and forecasts for urbanization rates and urban populations from the UN Population Division's World Urbanization Prospects 2018 report.

D. Bars show average urbanization rates within regions. Lines show interquartile range of the urbanization rates of individual countries within regions.

al. 1998; Brody 2013). Evidence suggests that urbanization, of itself, has generally caused increased consumption of commodities. But this effect is not uniform. High population density in the cities of advanced economies is associated with reduced per capita consumption of energy. Given the sharp increase in the urban population expected over the next 30 years, it is critical to understand how urbanization can affect demand for different types of commodities, beyond the broader impact of population and income growth.

BOX 2.1 Urbanization and commodity demand *(continued)*

Against this backdrop, this Box reviews the literature on the relationship between urbanization and commodity demand and asks the following questions:

- What is the nature of urbanization?
- What are the channels through which urbanization can affect commodity demand?
- What are the empirical effects of urbanization on commodity demand?

The nature of urbanization

While the share of the population living in urban areas has risen globally, the density of urban areas varies significantly across and within countries and has changed over time.

Defining urban areas. Definitions of what constitutes an urban area differ greatly between countries, with officially designated minimum sizes ranging from 200 people in Denmark and Sweden, to 50,000 in Japan (figure B2.1.2; United Nations 2019). Furthermore, some countries use metrics such as population density instead of population size. In addition, definitions of what areas to include in urban regions vary substantially across countries.[a] For example, suburban areas may not be officially part of the city but may be considered for economic purposes part of the urban area. The size of defined urban areas varies considerably, from megacities containing 10 million or more people, to urban areas with fewer than 300,000 people. While a majority of the world's population lives in an urban area, two-fifths live in urban areas of less than 300,000 people.

Density of urban areas. On average, the larger a city is, the denser it is. However, similar-sized cities can vary substantially (Dijkstra, Florczyk et al. 2020). Cities in Asia have much higher density than cities in the United States—among the 100 largest cities in the world, 9 of the 10 least densely populated are in the United States. Population densities of large cities in India are orders of magnitude greater than these U.S. cities. The types of density also vary. For example, the skyline of cities can be vastly different between countries. Richer cities tend to be more "pyramid shaped"—i.e., with more taller buildings and skyscrapers, whereas low- and lower-middle-income cities tend to be "pancake-shaped" or flatter. In

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[a] To facilitate the comparison of urban areas, the United Nations endorsed a new methodology to define cities, towns, and rural areas based on total population and population density within population grids (Dijkstra, Florczyk et al. 2020; United Nations 2020). Under this definition, the share of the population living in urban areas increases substantially (in 2015, by 22 percentage points), in part because several large countries classify most towns as rural areas (Dijkstra, Hamilton et al. 2020).

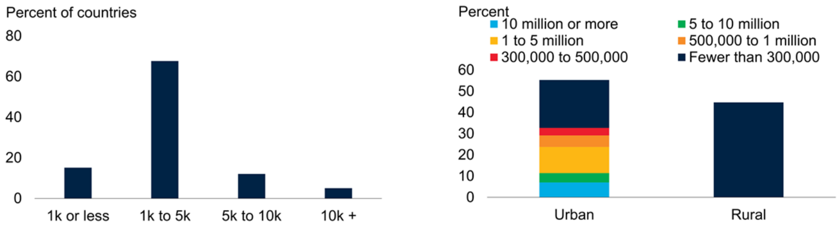
BOX 2.1 Urbanization and commodity demand *(continued)*

FIGURE B2.1.2 Urban population share and population density

The population threshold for defining an urban area varies greatly across countries. Based on official definitions, about 60 percent of the world's population lives in urban areas. About 50 percent of the urban population lives in cities of less than 300,000 people. Population densities of the largest EMDE cities, especially in Asia, are an order of magnitude greater than cities in the U.S.

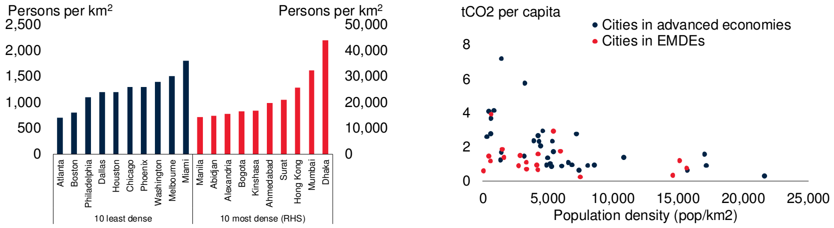
A. Population threshold for "urban area"

B. Global distribution of population, by city size



C. Population density of cities

D. Population density and carbon emissions in selected cities



Sources: Our World in Data; UN Habitat (2020); World Bank.

A. Chart shows the variances in definitions among countries for the minimum number of inhabitants needed for a settlement to classify as an "urban area." Sample includes 100 countries. Some countries do not rely on a population threshold and instead consider other metrics, including population density, and are therefore not included here.

B. Chart shows the percent of the world's population living in urban and rural areas, with urban areas split by size of city.

C. Population density of world's 100 largest cities. Figures show the 10 least dense and most dense cities. Data from 2014.

D. Y-axis shows metric tons of CO2 emissions per capita from transport. X-axis shows population density of 40 major cities. Data are from 2016 to 2019.

EMDEs, the combination of high population density and low-rise residences is prone to over-crowding, and reduced quality of life (Lall et al. 2021).

Changes over time. Cities can either grow outward, inward (infill of undeveloped spaces), or upward. In low-income and lower-middle-income countries, 90 percent of urban built-up area expansion occurred as horizontal or outward growth between 1990-2015, and only 10 percent as infill. In high-income

BOX 2.1 Urbanization and commodity demand *(continued)*

countries, however, around 30 percent occurred as infill (Lall et al. 2021). Population densities have generally increased, however, as urban populations have grown faster than urban areas have expanded. Between 1990-2015, global population densities of cities rose by 8 percent, with larger cities experiencing the biggest increase in density (Dijkstra, Florczyk et al. 2020). In contrast, small cities (less than 250,000 people) experienced declines in population density.[b]

Channels: From urbanization to commodity demand

Urbanization affects commodity consumption through several channels. These include the impact of urbanization on transport behavior, infrastructure needs, household characteristics, and consumer choice.

Transport. Urbanization has the potential to either raise or lower energy demand from transport. Studies which find urbanization reduces energy demand from transport typically focus on the fact that high density neighborhoods facilitate journeys by foot or by bicycle, and effective mass transit systems provide alternatives to personal motorized vehicles (figure B2.1.3; Brownstone and Golob 2009; Kahn 2000; Liddle and Lung 2010; Newman 2006). In contrast, studies which find that an increase in the urban population increases transport energy demand focus on factors that can result in increased journeys. In the absence of mass transit systems, rising urban populations can result in increased dependence on cars, as residences and workplaces are typically separated in cities (Glaeser and Kahn 2010; Jones 2004; Marshall 2007). This issue can be exacerbated by "urban sprawl," which can lead to increased auto use (Burchell et al. 1998; Hankey and Marshall 2010; VandeWeghe and Kennedy 2007).[c]

In EMDEs the move from rural to urban areas may see a shift from mainly muscle-powered transport (e.g., walking or biking) to motorized transport (e.g., cars, motorcycles, and buses), leading to a net increase in energy consumption (Parikh and Shukla 1995). This is particularly the case in instances where cities have not been well planned (Wahba 2019). In addition, the reliance of cities on commodities produced outside their borders, such as food, can result in increased energy use as these products need to be transported and stored; this would not be the case for mostly self-sufficient rural areas (Parikh and Shukla 1995).[d]

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[b] In contrast, earlier studies found that population densities had decreased over time. This was because they had a higher estimate of the increase in urban areas due to different methodologies (Angel et al. 2016; UN Habitat 2020).

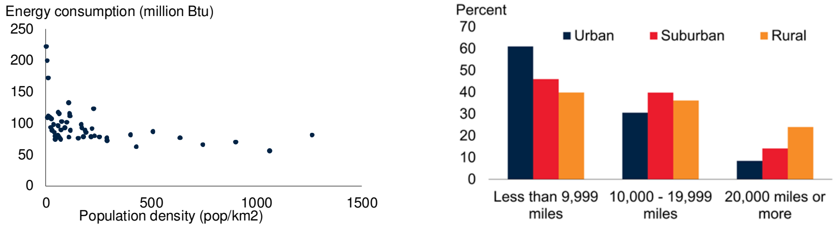
[c] Causation may also run in the opposite direction, whereby the development of the automobile facilitated lower-density cities.

[d] As urbanization facilitates economies of scale and specialization as part of the industrialization process, it may lead to the increased movement of raw materials and intermediate goods in the production process (Jones 1991, 2004).

BOX 2.1 Urbanization and commodity demand *(continued)*

FIGURE B2.1.3 Urban populations and transport-sector energy demand in the United States

Low levels of population density are associated with much higher energy consumption from transportation in the United States. Rural populations tend to drive more and walk less than their urban counterparts. Similarly, high rates of urban density facilitate the use of public transport, with commuter rates much higher in large, dense cities. Household energy use is higher in detached houses compared with apartments, and energy use is also higher in smaller households.

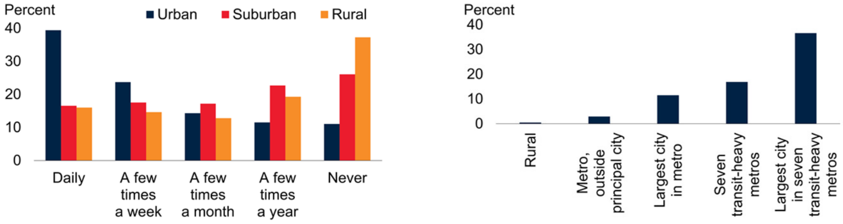


A. Population density and transport-sector energy consumption in the United States

B. Miles driven per year

C. Frequency of walking for travel

D. Share of workers commuting by public transport



Sources: Federal Highway Administration, National Household Travel Survey 2017; World Bank.

A. Vertical axis presents data for total energy consumption per capita in the transport industry for 50 U.S. states, whereas population density is shown on the horizontal axis. Data for 2019.

Infrastructure requirements. Densely populated cities have vast infrastructure needs, including mass transit, electricity generation, and water and sewerage services (Eberts and McMillen 1999). Economies of scale and network effects may, however, make the provision of the service more efficient (i.e., on a per capital basis). At the same time, it is possible that urbanization and high-density living creates new demands for infrastructure. For example, high-density urban populations have greater need for sewerage systems than low-density rural areas.

Household size and type of accommodation. An increase in the share of the urban population can lead to differences in household characteristics, with either

BOX 2.1 Urbanization and commodity demand *(continued)*

positive or negative impacts on energy consumption. Apartments are much more common in cities than in rural areas due to higher land costs. Apartments have smaller energy use than detached houses due to fewer exterior walls, which reduces energy loss from heating and cooling (Brounen, Kok, and Quigley 2012; Satterthwaite 2011). However, this may be partly offset by differences in household composition. Average household size tends to be smaller in urban areas, as young people move away from their family home and delay forming households (Cole and Neumayer 2004). Smaller households tend to have higher per capita energy consumption as they are less able to benefit from economies of scale in energy consumption compared with larger households (Liu et al. 2003).

Changes in the composition of energy demand. Urbanization can also lead to changes in the types of fuel consumed within a country. As households move from rural to urban areas, they typically move from more basic forms of energy, such as biomass, toward more modern energy forms, such as electricity from centralized power stations fueled by coal or natural gas (Barnes, Krutilla, and Hyde 2005). This shift has the potential to reduce commodity demand as the provision of energy in the form of centrally generated electricity or natural gas is typically more efficient (Pachauri and Jiang 2009; Poumanyvong and Kaneko 2010). However, greater access to better-quality, cheaper energy such as electricity may lead to increased consumption of energy (Gillingham, Rapson, and Wagner 2016; IEA 2008).

The "heat island" effect. Urban areas give rise to the "heat island" effect, whereby structures such as roads and buildings absorb and re-emit heat from the sun to a greater degree than natural landscapes (Imhoff et al. 2010). Urban areas, particularly cities with larger and more dense populations, are hotter than nearby rural or natural areas, although the effect can vary between cities depending on the extent of green space within them. These variations can increase energy demand for cooling in hotter countries and during summer; however, it can reduce energy demand for heating in countries with cold winters.

Increased consumer choice. Consumers living in cities benefit from a larger choice of goods and services which can lead to increased consumption by increasing access to new products. Access to larger markets enables producers and retailers to specialize and supply a wider variety of goods and services. All else equal, a rise in consumption due to increased choice, beyond that caused by increased income, would result in aincrease in commodity demand. For example, urban diets are typically more varied and include a greater share of meat and processed food, which require more energy and other commodities in their production (Hovhannisyan and Devadoss 2020; Regmi and Dyck 2001). However, as income is the primary driver of per capita commodity demand, and

BOX 2.1 Urbanization and commodity demand *(continued)*

higher incomes generate more choices for the consumer, these studies leave open the size and direction of the impact of urbanization on commodity demand.

Effect of urbanization on commodity demand: Empirical estimates

This section is based on a survey of literature on how urbanization affects commodity demand (Table 2.2). The research can be broadly split into two fields: studies that investigated the effect of the share of the urban population; and studies that delve deeper by considering urban density (differences between high- and low-density urban areas within a country). The majority of the studies on the share of urban populations used panel datasets with a wide range of economies. They focused mainly on aggregate energy consumption, although some looked at individual sources of demand for energy. This group included some single-country studies, with two for food consumption. In contrast, the studies examining urban density in individual countries covered AEs only (Canada, Japan, the Netherlands, and the United States) likely because of greater data availability. Their main focus was on sectoral demand for energy (e.g., transport or dwellings). All studies in the literature review controlled for per capita income.

Share of urban populations. Higher urban population shares were positively correlated with energy demand in almost all cross-country studies. One study found the relationship varied by income level, with a negative relationship for LICs, but a positive relationship for higher-income countries; this was attributed to efficiency gains arising from shifts to more modern fuels (Poumanyvong and Kaneko 2010). A study investigating metals consumption also found a positive impact of urbanization on demand (Baffes, Kabundi, and Nagle 2021). Three studies investigated food consumption and found little impact from urbanization after controlling for income (Hovhannisyan and Devadoss 2020; Pandey et al. 2020; Stage, Stage, and McGranahan 2010).

Urban density. Of the studies examining the impact of urban density, all found a negative relationship with energy demand. These studies considered a variety of energy uses, including for transport, dwellings, dwellings and transport together, and consumption from the service sector. [e] Higher-density cities had lower energy demand than lower-density ones, at least in advanced economies. The extent to which these results apply to EMDEs is unclear. Many cities in LICs, particularly in Sub-Saharan Africa, struggle with high road congestion and commuting costs

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[e] These studies considered various channels, including transport (Liddle 2004; Brownstone and Golob 2009); dwellings (Brounen, Kok, and Quigley 2012; Lariviere and Lafrance 1999); dwellings and transport together (Glaeser and Kahn 2010; Larson and Yezer 2015); and consumption from the service sector (Morikawa 2012).

BOX 2.1 Urbanization and commodity demand *(continued)*

due to poor planning, inadequate transport infrastructure, and limited public transit options, despite high population density (Hommann and Lall 2019).

Conclusions and policy implications

The share of the global population living in urban areas has risen rapidly over the past 50 years alongside a major increase in commodity consumption. While income and population growth have been the primary drivers of commodity demand over time, urbanization per se has also had an effect. In general, an increase in the share of the urban population is associated with increased energy demand per capita. But the quantitative impact will depend on the nature of urbanization in particular countries. Compact, high-density cities have lower per capita energy consumption than low-density cities, particularly in advanced economies, due to greater resource efficiency in heating, shorter distances between home and work and recreation, and economies of scale in mass transit.

With urban populations expected to continue to increase, strategic urban planning that increases population density, and integrates transport and land use, will become even more important in managing the impact of urbanization on commodity demand.[f] Key policy measures include the expansion of the capacity, affordability, and access of public mass transport systems. Fiscal policies can also play a role, for example, fuel taxes have been shown to increase population density and preserve open space (Creutzig 2014; Creutzig et al. 2015). Many countries may be close to the upper limit of these taxes, however, since their burden falls on workers in certain urban sectors (e.g., truckers and taxi drivers).

In addition, well-devised incentives and regulations are required. Incentives for reduced energy consumption, including upgraded insulation in existing homes, provide a public good. Building codes can ensure that new homes meet high energy-efficiency standards. Regulations to reduce the use of private vehicles in congested districts have proved effective. Zoning laws to encourage intensification through infill housing, and building up instead of out, can help reduce long commutes, increase usage of public transit, and lower energy use and greenhouse gas emissions (Lall et al. 2021). Early planning and installation of transportation infrastructure is particularly crucial in rapidly growing cities as it can help guide and shape future urban growth (Hommann and Lall 2019).

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f. The development of green and sustainable cities is a key component of the World Bank's Climate Change Action Plan, and in line with the UN's Sustainable Development Goal 11 to make cities and human settlements inclusive, safe, resilient, and sustainable (World Bank 2021c).

Innovations on the demand side have expanded the use of oil in new sectors, but also reduced its use due to efficiency improvements. For example, innovations in the petrochemicals industry have led to new products such as plastics and fertilizers, while the development of the jet airplane made long-distance travel and tourism available to a mass market. This, in turn, increased demand for oil—jet fuel currently accounts for around 5 percent of global oil consumption. At the same time, innovations have sharply improved the efficiency of oil consumption, reducing the aggregate increase in demand for oil. The average fuel consumption of a new aircraft fell by 45 percent between 1968 and 2014, an average annual reduction of 1.3 percent (Kharina and Rutherford 2015).

Disruptive innovation has been common throughout history. It has been a major cause of transformation in the structure of commodity demand, and a crucial factor for economic growth (Aghion, Antonin, and Bunel 2021).[5] The industrial revolution led to massive, permanent, demand shifts for several commodities. Inventions during the 18th century transformed the textile industry from its cottage structure (i.e., home-based factories employing a few workers) to the world's largest industry. Innovations included John Kay's flying shuttle in 1733, James Hargreaves' spinning jenny in 1764, and James Watt's steam engine in 1769, which all led to cotton replacing wool and flax.

The steam engine revolutionized land and ocean transport. Iron replaced timber for ship bodies, and coal-fired steam engines replaced cotton sails. The internal combustion engine revolutionized transport (both ocean and land) in the first half of the 20th century, replacing coal with gasoline and diesel. In the second half of the century, kerosene became the main fuel for air transport. In addition, innovations in chemistry saw synthetic rubber overtake the use of natural rubber in the production of tires (figure 2.6). Unlike the routine substitutions that occur in response to a change in relative prices, substitutions from transformative technical change are usually nonreversible.

Two notable technology-driven transitions are currently underway. The first concerns communications and information storage. The inventions of the telegraph and subsequently the telephone led to increased use of copper wire in place of messengers. More recently, the development of the Internet, mobile devices, wireless technology, and fiber optics have reduced the commodity intensity of much consumer and business activity. For example, video conferencing tools have reduced the need for personal and business travel. For more than five centuries (since the invention of the printing press in the mid-15th century) information was typically stored and transmitted on paper made from natural fiber. Following advancements in digital technology during the late 20th century, paper is being rapidly substituted by digital storage and reading devices, thus substituting natural fibers with rare earth metals and energy. The second notable development, which has far more important implications for commodity demand and

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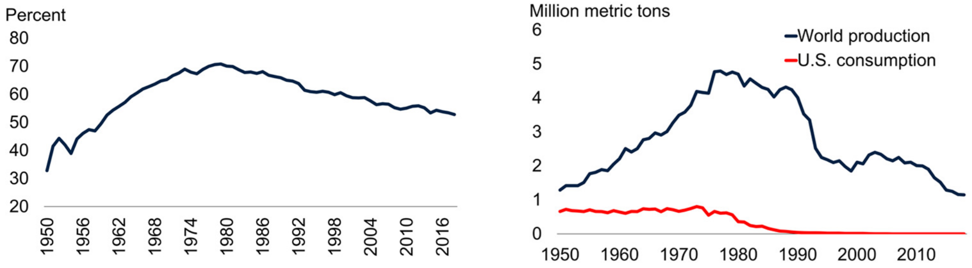
[5] The causation is not always unidirectional. Innovation may be induced by price changes. Discussions of substitutability go back to Hicks (1932), who argued that a change in the relative prices of the factors of production spurs innovation. Hicks' hypothesis, known as induced innovation hypothesis, has been tested extensively, including in Hayami and Ruttan 1970; Olmstead and Rhode 1993; Hanlon 2015; Newell, Jaffe, and Stavins 1999.

FIGURE 2.6 Drivers of commodity demand: technology, innovation, and policies

The invention of the steam engine led to steamships replacing sailing ships, and wooden frames along with cotton- and linen-based sail cloth (all agricultural commodities) replacing steel frames (made from iron ore) and steam engines (running on coal instead of wind energy). Innovations in chemistry led to synthetic rubber and polyester (made from crude oil) displacing natural rubber and cotton (agricultural commodities). Commodity consumption can also be sharply influenced by government policies. Concerns about the health impact of asbestos in construction materials, and lead in paint and gasoline, led to their use being gradually phased out and eventually banned. Aided by improvements in battery technology, charging infrastructure, and government incentives, the share of hybrid and electric vehicles have enjoyed impressive demand growth.

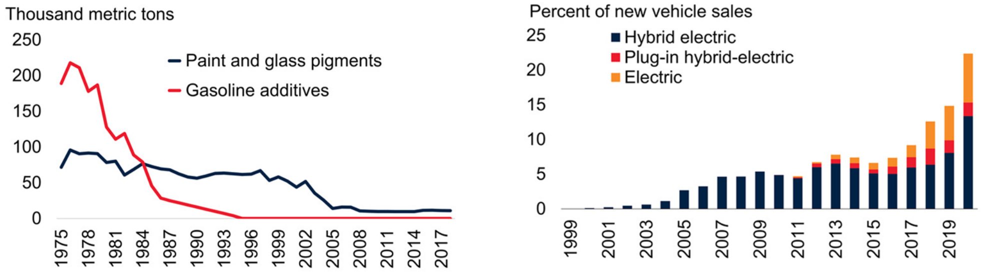


A. Share of synthetic rubber in global rubber consumption

B. Asbestos use

C. Consumption of lead in the United States

D. Sales of alternative vehicles in the U.S.



Sources: International Rubber Study Group; U.S. Department of Commerce; U.S. Geological Survey; World Bank.
A. Synthetic rubber is a substitute of natural rubber.

has only just begun, is the energy transition away from fossil fuels. Box 2.2 summarizes aspects of historical and current structural changes.

Country-level policies

Changes in government policies have resulted in major changes in commodity demand. Governments routinely use subsidies and taxes to incentivize or discourage the consumption of commodities. For example, energy subsidies are prevalent in most countries (both in terms of production subsidies as well as consumption subsidies) and are often used to lower the cost of energy for consumers, which would typically lead to an increase in consumption. At the same time, to reduce pollution, fuel taxes are often used to reduce driving and consumption of gasoline or diesel. More recently, several countries have introduced special taxes on single-use plastics to address rising concerns about plastic pollution in the oceans.

Governments have sometimes introduced outright bans on the production or use of dangerous or unhealthy commodities. For example, growing awareness of the adverse health effects of lead poisoning saw the use of lead in gasoline, paint, and plumbing gradually phased out in the U.S. This began around 1970 and most other countries followed suit. More recently, China has implemented a range of regulations to improve air pollution in cities, including restrictions on metal smelting.

International policies

Throughout the 20th century, there have been numerous international commodity agreements (ICAs) that had a major impact on consumption patterns.[6] These agreements, often negotiated among both commodity-exporting and importing countries, were designed to mitigate the negative impacts of boom-bust cycles and reduce price volatility common to commodity prices. However, in practice, ICAs have distorted commodity markets by keeping prices high and stable, which encouraged consumers to reduce consumption, raise efficiency, or use substitute products (World Bank 2020). For example, the International Tin Agreement restricted the supply of tin and kept prices elevated for several years, but this resulted in the widespread substitution of tin by aluminum, especially in the beverage can industry. All efforts to manage non-energy commodity markets through international agreements have failed.

The Organization of the Petroleum Exporting Countries (OPEC), is the only remaining example of a major ICA. OPEC was founded in the 1960s with members coming together to negotiate better prices for oil and ultimately to use their market power to influence oil prices. OPEC interventions in the oil market have been frequent during the past 20 years, albeit with mixed success (Baffes et al. 2015). Notable examples include OPEC's decision to abandon quotas in November 2014 and more recently to introduce massive cuts (in partnership with other countries) following the collapse in demand due to COVID-19 (World Bank 2020). Similar to other production agreements, OPEC's' historical attempts to manipulate prices have triggered other market forces—by keeping prices high they have encouraged consumers to reduce consumption by increasing efficiency, substituting other fuels for oil, and inducing innovation in the production of crude oil. However, the group continues to actively manage its production of crude oil.

While earlier international agreements were motivated by economic objectives, more recent agreements reflect environmental and climate change concerns. For example, the Montreal agreement in 1987 began the gradual phase-out of the use of

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[6] Commodity agreements have covered the entire spectrum of commodity markets and have been researched in the literature, including for coffee (Akiyama and Varangis 1990), tin (Chandrasekhar 1989) and natural rubber (Verico 2013), as well as groups of non-oil commodities over time (Gilbert 2011; Roberts 1951; Davis 1946).

BOX 2.2 Substitution among commodities: Reversible and permanent shifts

Substitution among commodities is a key feature of market behavior. Substitutions of one good for another may follow changes in relative prices or incomes, with technology remaining basically the same. This often involves routine, reversible, shifts among similar commodities, e.g., natural gas for oil, or plastic for paper packaging. However, the underlying cause of transformative substitutions since the industrial revolution has been the development and adoption of new technologies. Historical examples are the replacement of animal and wind power by steam, or the substitution of jet fuel for bunker oil in transcontinental travel. Technology and policies in response to climate change could drive a new transformation, to a low carbon-emission economy. These forces will profoundly transform the structure of commodity consumption over the next few decades. The metals and other materials required to produce clean energy could see a strong rise in output, while the consumption of fossil fuels will start a permanent decline.

Introduction

Substitution between commodities is a routine but key feature of markets. For example, in many countries over the past 15 years natural gas has been supplanting coal for the generation of electricity. This substitution represents the normal functioning of the market mechanism, as an increased global supply of gas (especially due to rising U.S. shale gas production) caused a decline in its relative price that induced a matching increase in demand. In 2021, a surge in natural gas prices led to a reversal of this change, with countries switching to coal (and even crude oil) as fuel for electricity generation (World Bank 2021b).

Substitution among materials used as inputs in the production of final goods can take place at both short- and long-term horizons, as well as within and across commodity groups (Tilton and Guzmán 2016).[a] If a good or service can be provided more cheaply via the use of a different commodity, consumers will switch. In the long run, such substitution of inputs, in response to price changes, or other incentives, can occur on a much larger scale, as new capital equipment and production processes move to the least-cost options.

Substitution is very common as a response to price (or relative scarcity) changes among commodities belonging to the same group. In agriculture, soybean oil is a close substitute to palm oil for human consumption, while soybean meal and

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[a] As Wellmer (2012, p. 11) noted: "… we do not consume resources per se but their inherent functions or their physical and chemical properties. We do not need one tonne of copper: we need its electrical conductivity for transmitting power supply or transferring messages via electric pulses in telephone wires. This latter function can be ensured via fiber cables, directional antennae or mobile phone. So, we have substitution in the narrow sense (glass fiber vs. copper) and functional substitution to obtain the same function. Every technical solution has its own raw material profile."

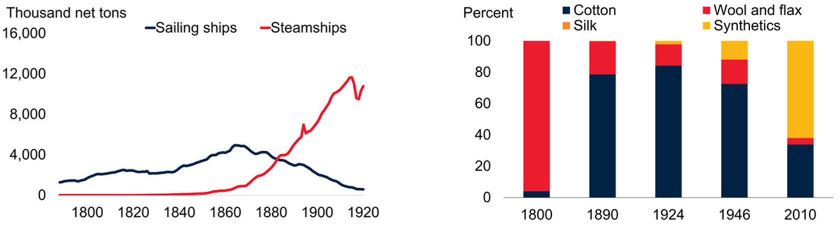
BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

FIGURE B2.2.1 Historical episodes of substitution

By 1890, steam accounted for more ship power than sail, and by 1920 the replacement was almost total. Following the introduction of aluminum beer cans in the mid-1960s, their share of shipments reached three-quarters by 1986 (they replaced refillable glass bottles and tin cans). In the early 1800s, wool and flax dominated fiber consumption. They were gradually replaced by cotton during the next 150 years. After WWII, synthetic fibers accounted for more than half of global fiber consumption. When prices of oil increased seven-fold after the oil crises of the 1970s, crude oil's share in electricity generation began to rapidly decline, replaced by natural gas and, to a lesser extent, coal. More recently, the share of renewable energy in electricity generation has risen rapidly, driven by a sharp decline in renewable energy costs.

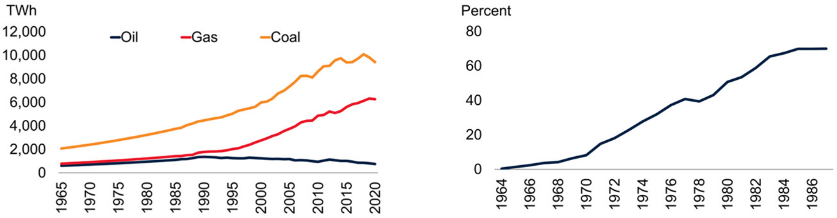
A. Shipping capacity in the United Kingdom

B. World fiber consumption, by type



C. Global electricity generation, by fuel

D. Share of aluminum cans in beverage containers



Sources: Authors' calculations; BP Statistical Review; World Bureau of Metal Statistics; World Bank.
A. Denotes ocean transport capacity of ships registered in the U.K.
C. TWh stands for terawatt hours

maize are substitutes for animal feed. In energy, different fuels are direct substitutes, such as coal and natural gas in electricity generation; while in metals, tinplate steel has been replaced by aluminum for beverage containers. Examples of substitution across groups include transport, where ethanol (from maize or sugarcane) and biodiesel (from edible oils) can be substituted for gasoline (from crude oil), and the beverage container industry, where plastic bottles (a by-

BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

product of crude oil) or paper (agriculture-based) can be substituted for aluminum cans (metal-based). Such substitutions can later be reversed just as easily if relative prices go back to their previous level.

Substitution can also be driven by policies. Domestic policies often change the relative prices of commodities. For example, many oil-producing countries subsidize oil, thus encouraging its consumption at the expense of other energy sources. Trade policies (such as tariffs), and industrial policies (such as protection of agriculture) can induce substitution. Regulations to protect the environment or to control dangerous substances also affect the composition of commodity demand. Changing consumer preferences can also lead to substitution. For example, following environmental concerns, consumers have been seeking to minimize the use of petrochemical-based materials (such as plastic) by natural or biodegradable alternatives (such as paper).

Historically, major, more permanent changes in the use of commodities have been caused by innovation. Technical advances, and their adaptation by entrepreneurs, have profoundly transformed existing economic structures. The resulting transformational commodity substitutions are not easily, and hardly ever, reversed. For example, the introduction of jet planes caused a switch from bunker oil to kerosene as the source of power for transcontinental travel. Moreover, transformational substitutions can cross commodity groups. The invention of the internal combustion engine eventually led to the substitution of metal and oil for horses and animal feed. There is no turning back from this kind of transformational change—also known as disruptive innovation or creative destruction (Aghion, Antonin, and Bunel 2021).

It can be challenging to identify episodes of transformative commodity substitution from routine substitution because forces like technological advances, resource discoveries, innovation, population growth, urbanization, and income growth are endlessly intertwined.[b] The distinction, however, can shed light on the economic history of commodity use. And it is especially relevant today in what is likely the beginning of an era of accelerated technical change and innovation under the impetus of climate change and government policies to mitigate its impact.

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b. Theoretical discussions on commodity substitution and its relationship with innovation and prices go back to Hicks (1932), who wrote (pp. 124): "… a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind—directed to economizing the use of a factor which has become relatively expensive." Hicks' view, which was later coined the induced innovation hypothesis, has been discussed extensively, including in Hayami and Ruttan (1970); Olmstead and Rhode (1993); Newell, Jaffe, and Stavins (1999), and Hanlon (2015). Substitutability among commodities has been cited as the antidote to resource scarcity (Goeller and Weinberg 1978; Pei and Tilton 1999).

BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

Against this background, this box examines the following questions:

- What have been the quantitative drivers of commodity substitution episodes over the past half century, and how have they affected commodity demand?
- What will be the role of commodity substitution in the energy transition that is only just under way?

The Box confirms that new technologies and innovation have been the key forces behind long-term substitution, especially after the industrial revolution. On some occasions, however, policies too have played an important role. Each of the substitution episodes saw substantial changes in commodity demand, however there were important differences. For some episodes substitution has been complete, with one commodity completely replaced by another, while for others substitution is incomplete, with both commodities still used, albeit with a smaller share for the original commodity.

As efforts to transition away from fossil fuels accelerate (in the context of energy transition and pollution), substitution is expected to occur across commodity groups. Consumption of fossil fuels is likely to decline while consumption of the metals which are associated with production of renewable energy and electric vehicle technology will rise. Demand for agricultural commodities may also increase, depending on whether policy announcements regarding the production of biofuels materialize.

How have past substitution episodes affected commodity demand?

Substitution among commodities on the demand side has played a key role in economic development at the macro level and has affected the entire spectrum of industries. To illustrate this, this section examines the role of substitutability in three industries: transportation, packaging, and electricity generation.

Transportation

Substitution, driven by innovation, has been an ongoing process in the transport industry since the industrial revolution, with profound implications for economic development. In the late 18th century, the recently invented steam engine was first adapted to the textile industry. Innovations over the next century led to its widespread adoption for land and ocean transport. As animal traction was replaced by trains, animal feed gave way to coal as the source of power. Steel and iron replaced wood for the bodies of ships, and coal-powered steam engines replaced cotton and linen sail cloth. More generally, the industrial revolution brought a transition from agricultural commodities to mineral energy and to metals (Lundgren 1996).

BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

In the late nineteenth and early twentieth century, technological developments in the transportation industry induced further substitution among agricultural and energy commodities. The invention of the car saw three competing technologies in the late nineteenth century. The first cars were powered by steam and electricity and led to the partial replacement of animal traction, which meant that food commodities were largely supplanted by coal and coal-powered electricity. Next, the first-generation internal combustion engine vehicles that used biofuels replaced the early electric vehicles (Kovarik 2013). Later, vehicles powered by gasoline and diesel became the dominant form of ground transport. Similar trends took place in ocean transport where steam engines were replaced by internal combustion engines, again substituting diesel and bunker fuel for coal.

More recently, biofuels have again emerged as a substitute fuel for transport. Numerous countries legislated biofuel policies in the late 20th century, mostly in the form of mandates (de Gorter and Just 2009). These include the use of maize-based ethanol in the United States, edible oil-based biodiesel in the European Union, and sugarcane-based ethanol in Brazil. More recently several other countries (including China, Indonesia, and Thailand,) have introduced biofuel policies and are expected to produce substantial amounts of biofuels—if or when policies are enacted. Biofuels currently account for about 4 percent of total land allocated to food crops, and less than 2 percent of global liquid energy consumption. Substitution in the transport industry continues into the 21st century with the internal combustion engine vehicles being replaced by electric vehicles (see next section).

Packaging: Beverage and bottle industries

Until the 1960s, glass, steel, and tinplate were the main materials used to manufacture beverage containers (chiefly for soft drinks and beer). However, the emergence of aluminum in the 1960s, with its superior properties (being lightweight, easy to recycle, and featuring technological developments like the pull-up and crimp can) significantly changed the beer industry, and to a lesser extent the soft drink sector (Nappi 1990). The share of aluminum cans used in the beer industry in the U.S. reached 80 percent by 1986, with the tinplate cans being completely replaced. In the soft drink industry, however, the share of aluminum cans was limited by the dramatic rise of plastic bottles following their introduction in the late 1970s.

Aluminum's expanded use at the expense of tin was also aided by the International Tin Agreement, which kept tin prices artificially high through the management of buffer stocks (see Chapter 1). The agreement, first negotiated in 1954 with the objective of maintaining tin prices within a desired range through

BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

the management of buffer stocks, collapsed in 1985 following several years of insufficient funds to maintain stocks (Chandrasekhar 1989). Tin lost market share not only from technological advances of its competitors, but also by its own pricing decisions.

Innovation in beverage containers continues, particularly for soft drinks. Glass, plastics, and increasingly paper (e.g., Tetrapak) dominate the bottle market, although aluminum remains the main material for the can industry. Substitution between these materials occurs when relative prices change. Environmental concerns, particularly regarding plastics, have also favored recyclable (aluminum, glass) and compostable (paper) containers. Thus, what initially began as substitution among metals turned into substitution between metals and energy (plastics) and, recently, between metals/energy and agriculture (paper).

Electricity generation

In the decade prior to 1972, global oil consumption was growing at almost 8 percent a year in response to the rapid post-war expansion of transport, industry, and electricity consumption (generated using crude oil). The use of oil in these industries was aided by artificially low prices (during 1945-72 oil prices averaged about $16/bbl in 2017 constant terms because of price controls by the Seven Sisters oil cartel) making it comparatively cheaper to coal. The cartel's control gradually weakened as the share of EMDE oil production increased.

The 1973 and 1979 energy crises, which resulted in a seven-fold increase in oil prices, set in motion powerful market forces and policies to reduce oil consumption and seek alternative supplies. Efficiency improvements, often mandated by government policies, led to reductions in the amount of oil used by the transport sector, while the use of oil for electricity generation was displaced by coal, nuclear power, natural gas, and renewable sources (such as hydro and geothermal).

Coal's increasing use in electricity generation was encouraged by both national and international policies. The International Energy Agency's 1979 Principles for IEA Action on Coal directive required member countries to promote the use of coal as an alternative to crude oil and minimize the use of crude oil in electricity generation including by preventing new or replacement oil-fired capacity (IEA 1979, 1995). This was complemented by domestic policies, such as the U.S. Powerplant and Industrial Fuel Use Act of 1978, which mandated that no new baseload electric power plant could be constructed or operated without the capability to use coal or another non-oil/gas alternate fuel as a primary energy source.

BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

What will be the role of commodity substitution in the ongoing efforts of energy transition?

Efforts to decarbonize the global economy will induce further substitution among commodities, with important implications for commodity demand. This will occur across several fronts, including both the source of energy as well as its use.

Electricity generation: Substitution of fossil fuel commodities by metals

As discussed in Box 2.3, the energy transition is expected to see renewable energy replacing fossil fuel energy in electricity generation, which entails a sharp increase in demand for the metals and minerals used to produce renewable energy. This substitution is being driven by both demand and supply factors (IPCC 2021). Demand has shifted in response to changes in consumer preferences (e.g., growing interest in renewable energy and installation of solar panels), as well as policies (such as tax incentives for solar installation or purchase of electric vehicles, and the use of carbon pricing mechanisms). In terms of supply, technological developments have led to sharp reductions in the cost of renewable energy, increasing its relative competitiveness.

Transport: switch to electric vehicles, batteries, and biofuels

Transitioning toward a lower carbon energy environment will radically transform the transportation industry. Over the next decade, land transport will see large-scale replacement of gasoline- and diesel-powered vehicles by electric vehicles (EVs). Initially, EVs faced numerous headwinds, including high prices, long charging times, sparse charging stations, and limited driving range. However, aided by improvements in battery technology and charging infrastructure and government incentives, EVs have recently enjoyed impressive demand growth. In 2018, the global electric car fleet, at 5 million units, was up 2 million from the previous year (IEA 2019a). In the United States, electric and hybrid vehicles in 2021 accounted for nearly 10 percent of total passenger vehicle purchases. China is currently the world's largest EV market, followed by Europe and the United States. Norway has the highest use of EVs, at 46 percent of recent vehicle sales. Growth of the EV market share is expected to accelerate, as numerous countries have set high targets for phasing out new gasoline and diesel-powered vehicles.

EVs will induce substitution of commodities because of their fuel requirements—which favor sources of energy that generate electricity (most likely renewables) over crude oil—as well as their physical design. An electric vehicle, for example, contains four-times more copper (for the battery, motor, and wiring) than an internal-combustion engine vehicle. Large volumes of copper will also be needed

BOX 2.2 Substitution among commodities: reversible and permanent shifts *(continued)*

for the EV charging infrastructure. For a standard battery pack with the most common battery chemistry, the main materials are aluminum, copper, cobalt, graphite/carbon, lithium, nickel, and manganese.

Electric technology is less suited to shipping and air transport, but these sectors may find alternative substitutes to petroleum-based fuels such as hydrogen or biofuels. Hydrogen can be produced from water using either natural gas (although this process produces carbon emissions), or electrical energy. Biofuels currently account for about 2 percent of global liquid energy consumption. Biodiesel produced from agricultural products or waste products may also be used as a low- or zero-carbon alternative, as the feedstock comes from plants and trees that absorb carbon as they grow. The International Energy Agency estimates that a four-fold increase in biofuels production by 2050 would be needed to achieve a net-zero emissions objective (IEA 2021a). Several countries (including China, Indonesia, and Thailand) have recently introduced biofuel policies, which could potentially produce substantial amounts of biofuels if enacted. However, the policy-driven expansion of biofuels is a highly controversial and hotly debated topic in terms of its environmental benefits and its impact on food prices.

Conclusion

This box examined historical commodity substitution in three sectors (beverage packaging, electricity generation, and transport) and analyzed how substitution may affect commodity demand due to the energy transition. Ocean transport has undergone two complete substitution cycles (from sail ship to steam ship and from steam ship to bunker fuel and diesel). Both cycles were driven by technology and innovation, and the substitution was complete, resulting in large changes in commodity demand. Substitution in retail packaging was also driven by technology and innovation, with a shift from tinplate steel to aluminum (and later to plastic bottles, and more recently paper). Substitution in electricity generation reflects a combination of innovation (such as the introduction of nuclear power) and government policies. For all three sectors, substitution continues today because of advances in technology (e.g., falling cost of solar energy), policies to limit greenhouse gases (e.g., carbon-emission pricing, biofuel mandates), and consumer preferences (e.g., for recyclable or compostable materials in packaging).

The ongoing energy transition is likely to cause major substitution among commodities. Consumption of metals is likely to increase considerably at the expense of fossil fuels (Boer, Pescatori, and Stuermer 2021). Depending on policies, the use of biofuels for transport may increase considerably, effectively substituting fossil fuels by food commodities.

chlorofluorocarbons (CFCs), due to their detrimental impact on the ozone layer. An example of international action for health reasons is the outright ban on asbestos in 16 countries (2003), which followed the accumulation of scientific evidence on the carcinogen. More recently, the use of high-sulfur fuels in shipping is starting to be phased out under the agreement known as IMO 2020 (World Bank 2019). Of note are efforts to combat climate change by reducing greenhouse gas emissions, including the signing of the Paris (2015) and Glasgow (2021) agreements (IPCC 2021). Potential policies to accelerate the energy transition include carbon taxes, subsidies for renewable energy and electric vehicles (including battery development), and mandates to use certain types of commodities such as biofuels—all of which will materially alter commodity consumption patterns.

Modeling commodity demand

Following a literature review, this section estimates income elasticities of demand for energy, metals, and agriculture at the group level.[7] This enables a comparison across the three different commodity groups and a better understanding of the role played by identified drivers for each commodity.

Literature review on income elasticities

Estimates of long-run income elasticities of demand vary by commodity, between countries, and over time (Table 2.2). For energy, most studies have found an income elasticity of demand of less than unity (Burke and Csereklyei 2016; Csereklyei and Stern 2015; Jakob, Haller, and Marschinski 2012). That implies per capita energy consumption grows more slowly than per capita real GDP, consistent with a declining energy intensity of demand. Several studies have also found that income elasticities of demand for energy decline as income rises (Dahl 2012; Fouquet 2014; Jakob, Haller, and Marschinski 2012). An exception is Burke and Csereklyei (2016), who find the long -run income elasticity of demand increases as per capita real GDP rises. This finding likely reflects a country sample that included a number of low-income countries (LICs) whose long-run income elasticity of demand may initially be very low, as a result of their reliance on non-commercial fuels (i.e., biomass). As income rises beyond a certain low level, an increasing switch to purchasing fuel would imply a rising income elasticity, up until the switch is complete. Elasticities in LICs may also be kept low by policies such as energy subsidies (Joyeux and Ripple 2011).

For metals, the elasticity of income depends on the availability of substitutes and the range of uses. Because of its wide applicability, demand for aluminum grows more than proportionately with rising manufacturing output (i.e., with an above-unitary elasticity), while tin and lead, because of environmental concerns, grow less than proportionately

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[7] This section extends and builds on the work of Baffes, Kabundi, and Nagle (2021) by including agriculture and estimating income elasticities using GDP in PPP terms.

(i.e., with a below-unitary elasticity; Stuermer 2017). Fernandez (2018a) also finds a higher income elasticity of demand for aluminum (and nickel and zinc), than for lead.

Methodology and data

To estimate the relationship between income and commodity demand, a standard demand equation is used (Baffes, Kabundi, and Nagle 2022):[8]

$$c_t = \mu + \theta_1 y_t + \theta_2 y_t^2 + \theta_3 p_t + \varphi' X_t + \varepsilon_t \,, \tag{2}$$

where c_t denotes per capita commodity consumption at year t ; y_t is real per capita income in PPP terms, p_t is the real price of the commodity; and X_t is a h x 1 vector of control variables, such as fixed effects and various country-specific characteristics; ε_t is the stochastic error term; μ, θ_1 , θ_2 , θ_3 denote parameters; and φ' a vector, all to be estimated.

This approach is common in the literature (Adeyemi and Hunt 2007; Burke and Csereklyei 2016; Crompton 2015; Stuermer 2017). The quadratic income term y_t^2, intended to capture the nonlinearities discussed earlier, allows the calculation of income elasticities that vary across income levels and is consistent with an inverse U-shape theory of commodity demand.[9] Changes in commodity intensity of demand are captured by the control variables in X_t. Industrialization and urbanization are proxied, respectively, by the investment share and the urbanization share. A time trend proxies for technology-driven efficiency gains. By using group aggregates instead of individual commodities, the approach also controls for within-commodity group substitution (such as coal to natural gas) when overall demand for energy remains unchanged. However, it does not control for between-group substitution (such as coal to renewable energy made from metals).

Relationship (2) can be used to derive income elasticities as follows:

$$\eta_t = \frac{\partial c_t}{\partial y_t} = \theta_1 + 2\theta_2 y_t \,, \tag{3}$$

where η_t denotes the long-run income elasticity for the given commodity. Because η_t varies with income, it enables an estimation of whether consumption of a commodity plateaus as income rises. A large and positive value for the coefficient on y_t indicates a high initial elasticity, while a large and negative value for the coefficient on y_t indicates a rapid decrease in the elasticity.

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[8] The model is estimated by the PMG estimation procedure, which assumes homogeneity across all long-run estimators but allows for differences across countries in the short term (Pesaran, Shin, and Smith 1999)—an appropriate assumption as demand tends to be more similar across countries over the long term than the short term. For more details on estimation see Baffes, Kabundi, and Nagle (2021). All variables are in logs.

[9] An alternative specification would include a cubic term, y_t^3, which would be consistent with an S-shape consumption path—low growth initially, high growth at medium income levels, and a return to low growth at high income levels. Bogmans et al. (2020) find evidence for an S-shaped curve in energy consumption. Because the sample in this Chapter has relatively few low-income countries (due to data limitations), the inverse U-shape seems more appropriate.

The model was estimated for energy consumption (weighted by calorific energy content), metals consumption (aggregated using physical weights; a robustness check weighting with nominal values was also conducted), and agricultural consumption (weighted by calorific values). Annual data from 1970–2019 for up to 77 countries were used in the analysis. GDP per capita in PPP terms was used.

Results

Results for the energy, metal, and agriculture group aggregates are reported in Table 2.3. The parameter estimates for both the income variables and price variables have the expected signs—positive for y_t, negative for y_t^2, and negative for p_t, thus confirming that consumption of the aggregate commodity groups increases as income grows, but at a decelerating rate. The estimates are all significantly different from zero at the 1 percent level. The estimates of this parameter for the metals aggregate are greater than for energy, and much larger than for agriculture, implying that metal consumption exhibits a stronger response to income and price changes. In addition, the results from the error-correction component of the model show that metals adjust to long-run equilibrium faster than energy and much faster than agriculture. This is consistent with the higher variability of metal intensity compared to energy and agriculture as well as the cyclical nature of metals, which tend to move in tandem with industrial activity (Roberts, 1996).

The estimated income elasticities of demand show a considerable drop as the level of per capita income rises (figure 2.7). A value of one indicates commodity demand grows at the same rate as income; larger than one it grows faster than income, and below one slower. A negative value indicates declining commodity demand as income grows.

When calculated at the median level of per capita income in 2020, the income elasticity of demand for metals was 1.0, followed by energy at 0.6, and agriculture at 0.2. All commodities show a decrease in income elasticity as income rises, starting high and approaching zero or turning negative at higher levels of income. This is consistent with the dematerialization hypothesis, which predicts a switch of consumption from commodity-intensive material goods to goods and services with a higher value-added component. It can explain the plateauing of commodity demand shown in figure 2.4—as income rises, commodity demand grows at a decreasing rate.

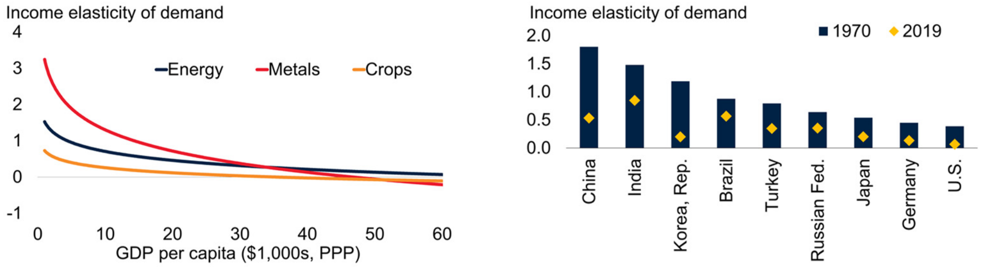
The evidence shows a significant variation of income elasticities across commodities. Those for metals and energy are well above unity at lower per capita incomes. As incomes rise, the elasticities decline, to below unity for both commodities at a per capita income of more than $20,000. The elasticity for metals declined faster, and was equal to energy at a per capita income level of $35,000 (PPP), and turning negative at $50,000. In contrast, energy had a positive income elasticity at all income levels. The estimate for the income elasticity of agriculture showed the least change for different levels of income. This estimate was less than unity even at the lowest income levels, which indicates that population is the primary driver of growth in agricultural commodities.

FIGURE 2.7 Income elasticity estimates

The income elasticity of metals was high at very low levels of income, but declined rapidly, reaching unity at about $12,000 per capita, and close to zero at the current level of U.S. income per capita. For energy, the initial elasticity was lower than for metals, but declined more slowly, and remained positive at the current level of U.S. income per capita. In contrast, agricultural elasticities were much lower than for energy and metals, indicating that population growth is the primary driver of agricultural consumption growth.

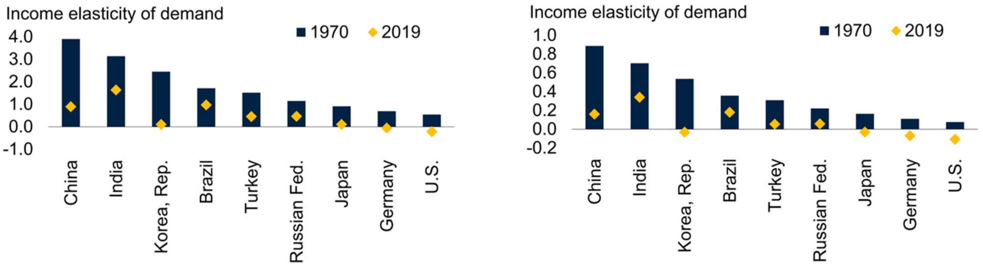
A. Aggregate income elasticity estimates

B. Energy income elasticity estimates for select economies



C. Metal income elasticity estimates for select economies

D. Agriculture income elasticity estimates for select economies



Sources: Authors' calculations; BP Statistical Review; U.S. Department of Agriculture; World Bank; World Bureau of Metal Statistics.
A. Lines show implied income elasticity of demand estimates derived from coefficients in Table 2.1.
B.-D. Bars and diamonds indicate income elasticity of demand estimates at 1970 and 2019 per capita income levels.

For each country, the implied path of income elasticities of demand over time can be derived. For most EMDEs, income elasticities started high and fell as they industrialized and developed. In the case of China, its demand elasticity for metals fell from 4 in 1970 to 0.7 in 2019, while for energy it fell from 1.5 to 0.5. This implies that China's demand for commodities is now growing more slowly than its economy—in the case of energy, at half the rate. In other words, the commodity intensity of demand is declining. In advanced economies, elasticities were lower in 1970, and by 2019 fell to near zero for energy and slightly negative for metals and agriculture, indicating a modest decline in per capita consumption as incomes rise from an already high level.

Scenarios of commodity demand growth

Several factors suggest the overall demand for commodities will grow more slowly in the decades ahead than in the past three decades. First, population growth is slowing. The world's population is expected to reach 9.8 billion by 2050 from 7.6 billion in 2020, a 30 percent increase (United Nations projection; figure 2.8). The increase over the preceding 30 years was over 40 percent. Moreover, almost all the expected growth will take place in EMDEs, especially in Sub-Saharan Africa, a region with the world's lowest per capita commodity demand.

Second, GDP growth is expected to slow. Consensus expectations for global growth 10 years ahead have repeatedly been revised down. The OECD's long-term forecasts for GDP growth in EMDEs indicate a slowdown in growth from an average of 4.8 percent per year between 2011-2019 to an average of 3.7 percent per year between 2021-2030, largely due to slower growth in China. As China slows, it is expected to increasingly shift toward less commodity-intensive activities. For metals, however, the concentration of projected GDP growth in regions with relatively low incomes is a positive factor because of the high income elasticities of demand at lower income levels. Growth will instead shift toward economies that are currently much less commodity-intensive than China.

A key question is whether India (with a similar population to China) or another group of EMDEs, such as those in Sub-Saharan Africa, could experience levels of commodity consumption growth commensurate to that of China. For India, this is unlikely, for two reasons. First, India is not expected to grow at the double-digit rates experienced by China through much of the 2000s. Second, India's economy is noticeably different, with the service sector playing a much larger role than it did in China at an equivalent stage in development. However, the current low levels of per capita commodity demand and expected population growth in other EMDEs and LICs represent a long-term future source of growth for commodity demand. As these economies develop and industrialize their commodity demand will rise, and given their very low levels of commodity consumption, they present a very substantial amount of pent-up demand.

A scenario of future commodity demand growth to 2030 can be derived from a simulation experiment based on the model described in section 3.2. The main inputs for the projection are the estimated income elasticities of demand, population growth forecasts from the United Nations, and estimates for GDP growth from the OECD.[10] The scenario focuses on EMDEs, given that the majority of population growth and commodity demand growth is expected to occur in these economies. The scenario does not take into account structural changes in commodity demand, however, such as the energy transition. The likely impact of the energy transition on commodity demand is explored in Box 2.3.

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[10] The OECD data contain growth forecasts for 31 advanced economies and 17 EMDEs which collectively account for more than 90 percent of global GDP. For countries without growth forecasts, annual growth was held constant at their 2010-19 average.

BOX 2.3 The energy transition: Causes and prospects

The energy transition—the shift away from fossil fuels toward zero carbon sources of energy—is already underway. While the speed and magnitude of the transition is uncertain, it will have significant implications for commodity markets. Consumption of fossil fuels is expected to decline, especially for coal and crude oil. In contrast, demand for metals and minerals is likely to see a boost from the transition, since renewable energy infrastructure, such as wind turbines and solar, require significant amounts of metal in their manufacture. For agriculture, a surge in demand for biofuels could see increasing competition for these crops with traditional food crops, putting upward pressure on prices.

Introduction

The energy transition refers to the shift from a predominately fossil-fuel-driven economy to one powered largely by zero-carbon energy sources. Such a shift is essential to sharply reduce greenhouse gas emissions (GHGs) to address global warming and achieve the objectives of the Paris Agreement. The transition is already underway; between 2000 and 2019, production of renewable energy increased by 300 percent, its share of total energy rose from 5 to 10 percent, and its share of electricity rose from 18 to 26 percent (figure 1). Despite this increase, the share of fossil fuels in total energy has remained relatively flat at the global level due to a fall in nuclear generation. Significant challenges remain, and further progress will be needed to avoid the worst outcomes of climate change.

While expectations for the speed of the transition vary, there is greater consensus that the energy transition will trigger a substantial change in the demand for commodities, leading to reduced demand for fossil fuels, particularly coal, and increased demand for the metals and minerals required for renewable energy infrastructure. Against this backdrop, this box examines the following questions:

- What is driving the energy transition?
- What are the challenges facing the transition?
- How fast is the transition expected to occur?
- How will it change patterns of demand for commodities?

What is driving the energy transition?

Government policies and consumer preferences. Policies are a potent tool in driving the energy transition. Almost all countries have signed up to the Paris Accord, and over 100 countries have either set or are considering net-zero targets, although timelines differ (IEA 2021b; van Soest, den Elzen, and van Vuuren 2021). Subsidies for renewable energy sources and associated technologies such as electric vehicles can encourage investment in these sources of energy. To reduce

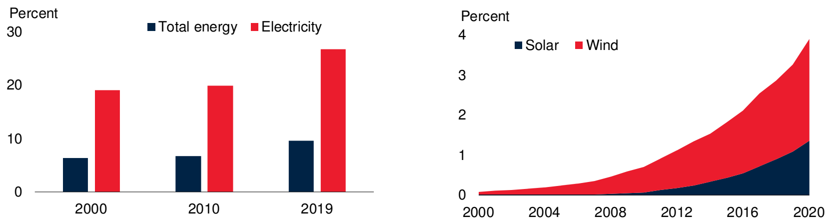
BOX 2.3 The energy transition: Causes and prospects *(continued)*

FIGURE B2.3.1 The energy transition and its drivers

Over the past 20 years the share of renewable energy has increased sharply, with rapid growth in solar and wind power. The energy transition is being assisted by government policies to reduce CO2 emissions, and by a sharp fall in renewable energy costs, both for electricity generation and storage.

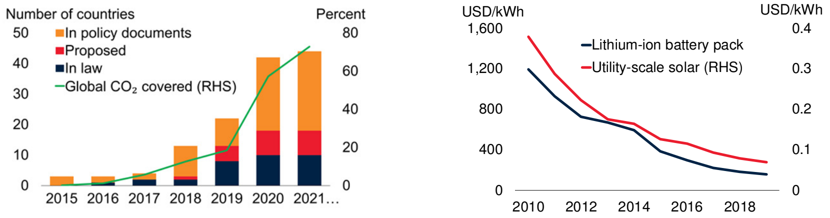
A. Share of renewables in global supply

B. Share of solar and wind power in global energy



C. Number of national net zero pledges and share of global CO2 emissions covered

D. Renewable generation and electricity storage costs



Sources: BP Statistical Review; International Energy Agency; IRENA; Our World in Data; World Bank.

A. Renewables include hydroelectric, solar, wind, geothermal, biomass, and other renewable sources.

D. Installed cost of utility-scale photovoltaic solar power, measured as dollars per kilowatt hour of generation. Consumer cost for lithium-ion cells, measured as dollars per kilowatt hour of storage.

the use of fossil fuels, many countries have enacted carbon taxes or carbon pricing (OECD 2021). Many private sector companies, including fossil fuel producers, have announced zero-target ambitions, often in response to pressure from investors. The energy transition has also been influenced by the growth of green investment, which is a component of the environmental, social, and corporate governance (ESG) investor movement. The Institute for International Finance estimates that ESG-related debt grew to $2 trillion in 2021Q1 (IIF 2021).

Declining cost of renewables. Improving technology and better manufacturing processes have resulted in a sharp decline in the cost of renewable energy. The price of utility-scale solar energy fell by 80 percent between 2010 and 2019, while

BOX 2.3 The energy transition: Causes and prospects *(continued)*

the price of onshore wind power declined by nearly 40 percent (IRENA 2020).[a] As a result, solar and wind energy are now the lowest-cost sources of new electricity in many parts of the world, including China, India, and the United States (IEA 2020). Installed capacity is expected to grow rapidly over the next five years, and costs are expected to continue to decline with technological improvements, increasing their competitiveness against traditional fossil fuels even more.[b] Decreasing costs of energy storage, including the development of new storage technologies, will be critical in facilitating a growing share of renewables in energy production. The ongoing development of low-cost lithium-ion batteries has been driven by the needs of the rapidly growing electric vehicle industry. In 2020, global EV sales rose nearly 20 percent, while sales of traditional cars declined. As storage costs continue to decrease and battery ranges improve, EV sales are expected to accelerate.

What are the challenges to achieving the transition to net-zero carbon emissions?

As the world economy has grown over the past 30 years, the carbon intensity of GDP has declined, but total emissions have nonetheless kept rising. Achieving a transition to zero poses several challenges.

Insufficient investment. If investment in fossil fuel production falls faster than investment in renewable production increases, it could result in a shortfall of energy. Investment in oil and gas production is currently at a level broadly in line with the International Energy Agency scenario for a net-zero transition (figure 2; IEA 2021c). Investment in low-carbon technology, however, is currently around one-third of what is required. The surge in energy prices in 2021 is a reminder of how rapidly fossil fuel prices increase when demand outstrips supply. Unexpectedly high energy prices, or interruptions to supply, could weaken political support for the energy transition.

Reserves and stranded assets. While renewables are increasingly the lowest-cost source of new energy, significant reserves of fossil fuels remain and are concentrated in EMDEs. With energy demand expected to continue to increase in EMDEs, particularly among low-income countries where access to energy has been limited, countries may choose to continue using fossil fuels, particularly if they have significant domestic reserves. Policy measures can be introduced to

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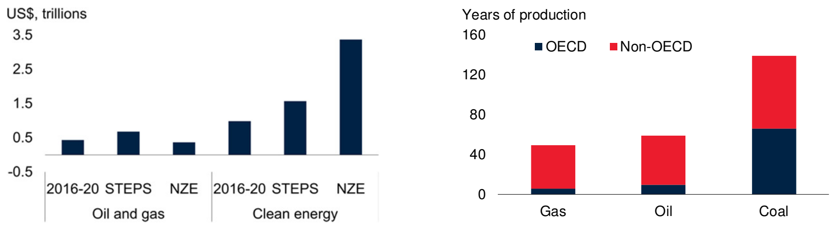
a. Utility-scale solar farms are large installations of solar panels. They vary in size from a few acres to more than 20 square kilometers. The costs of residential rooftop solar panels are higher due to their small size. Nevertheless, residential costs fell in the past decade by an estimated 47-80%, depending on the market.

b. The cost of solar panels and wind turbines increased in 2021 due to the broader rise in commodity prices, including the metals and minerals used in their construction (e.g., aluminum, silicon).

BOX 2.3 The energy transition: Causes and prospects *(continued)*

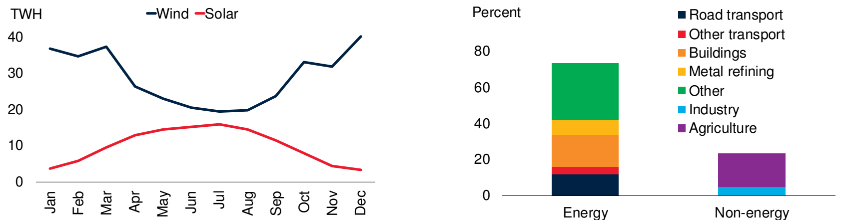
FIGURE B2.3.2 Challenges to the energy transition

The energy transition faces several challenges. Current levels of investment in clean energy are insufficient to offset the decline in oil and gas investment. Significant reserves of fossil fuels, particularly among EMDEs, encourages accelerated investment to sidestep the risk of stranded assets. Renewable energy also faces the issue of intermittency and seasonality. Other uses of energy will prove harder to decarbonize than road travel and electricity generation, and achieving a net-zero target in these industries will require significant technological developments, including in biofuels and the use of hydrogen.



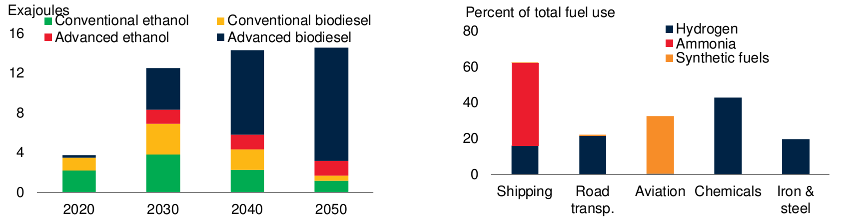
A. Investment needs

B. Fossil fuel reserves



C. Renewable generation, EU28

D. Share of global carbon emissions, by sector



E. Biofuel production under IEA's NZE scenario

F. Use of hydrogen fuels by sector under IEA's NZE scenario

Sources: BP Statistical Review; Eurostat; International Energy Agency; OurWorldinData; World Bank.

Note:. STEPS and NZE refer to the International Energy Agency's Stated Policies and Net Zero Emissions scenarios, taken from the *World Energy Outlook 2021*.

C. Chart shows monthly solar and wind energy production averaged over 2015-20. TWh stands for terrawatt hours. EU28 includes all European Union countries.

D. "Energy" refers to carbon emissions from the consumption of energy by sectors of the economy. "Other" includes all other carbon emissions from energy consumption by non-specified sectors of the economy (e.g., industry, agriculture). "Non-energy" refers to carbon emissions from other sources, such as industrial emissions from the manufacture of chemicals, and agricultural emissions from livestock and rice production.

E.F. Charts show scenario estimates for production of biofuels and hydrogen-based fuels, taken from the Net Zero scenario in IEA's *World Energy Outlook 2021.*

BOX 2.3 The energy transition: Causes and prospects *(continued)*

address this environmental impact, such as border carbon taxes, but equity considerations must also be taken into account. Stranded assets—resources tied to fossil fuels and no longer able to generate an economic return because of carbon pricing—present another set of challenges. For example, regulators have been focusing on the risks that such assets present to financial stability.

Energy storage. A notable problem with renewable energy is the issue of intermittency. Electricity generation can fluctuate based on weather, the time of day, and the season. For example, solar panels produce more energy when it is sunny, during the day, and during the summer. At present, renewable electricity generation requires either storage or back-up production for when renewable production drops. As renewable energy becomes increasingly widespread, this problem will become more acute, as has been seen in areas that have substantial solar capacity, such as California. Natural gas provides one method of backup generation of electricity, and it was so used during 2021 when drought and low wind speed reduced renewable production in many countries (World Bank 2021b). However, natural gas still produces CO_2 emissions, and as such low-carbon sources of backup power will be needed. Improved large-scale methods of storing electricity could help with the problem of interrupted supply. Measures to improve load-balancing, or adjusting electricity demand to synchronize with supply, will also be critical. For example, while solar production peaks in the summer and is lowest in winter, wind production tends to be higher in the winter and lower in summer. Integration of power markets across regions and countries, including transmission lines, can help balance generation from renewables.

Energy subsidies. Subsidies for traditional sources of energy remain high, despite progress in reducing them in recent years. In response to soaring energy prices in 2021, many governments in both advanced economies and EMDEs reintroduced subsidies or used price caps to prevent the higher cost of natural gas and coal from being passed onto consumers. To the extent that subsidies make fossil fuels cheaper, they will delay the energy transition.

Carbon-intensive industries and novel technologies. While the technology to move to zero-carbon electricity and road transport broadly exists, around one-third of emissions come from sectors that do not have an economically feasible alternative to fossil fuels. These sectors include ocean shipping, air transport, metal refining, and agriculture. Replacing crude oil-based fuels in shipping and air transport with battery power is not currently an option because of the length of journeys and the size of the vehicles. Many industrial processes, including the refining of metals, notably steel, are carbon-intensive—the smelting of iron ore into steel uses coking coal, and currently accounts for around 7 percent of global emissions. A potential solution could be biofuels for some forms of transport, or hydrogen, which could be used both as a fuel for transport, as well as a

BOX 2.3 The energy transition: Causes and prospects *(continued)*

replacement for fossil fuels, such as coal, in the smelting of steel (IEA 2019b; IRENA 2020). However, further technological development is required before these are viable solutions.

Agricultural emissions. Greenhouse emissions from agriculture will be a challenge. Agriculture tends to be very capital- and energy-intensive in advanced economies, whereas in EMDEs it is typically more labor-intensive. Agriculture also produces non-energy greenhouse gas emissions. These include the production of methane from livestock, especially cows, as well as from rice paddy fields. The euro area stands out for its energy intensity, which is driven by a few countries, notably the Netherlands and Belgium, which farm very intensively on small areas of land and use energy for heating and lighting. In contrast, southern countries have much lower energy intensities as they rely more on the sun.

How fast is the energy transition expected to occur?

While the transition is underway, the timing is uncertain and depends on the approach taken by governments, and on the pace of technological change. Several scenarios have been developed by both industry and international organizations (BP 2020; EIA 2021; IEA 2021c; Royal Dutch Shell 2021). Figure 3 shows two scenarios by the International Energy Agency.[c] The first is the stated policies scenario (the "business-as-usual" approach), which incorporates current government policies but no additional progress. The second is the net-zero emissions scenario, which assumes significant policy changes by governments as well as substantial technological development in renewable generation, storage, and carbon capture, and results in an energy transition fast enough to limit warming to 1.5 degrees.

Under the stated policy scenario, the use of coal is anticipated to have already peaked and is expected to gradually decline over the next 30 years, while demand for oil sees a slight increase, driven by demand from EMDEs, before plateauing and declining after 2035, but broadly unchanged from current levels by 2050. Natural gas consumption continues to rise, given its cleaner properties and use as a backup fuel for renewables. Demand for renewable and biofuels rises rapidly, approximately doubling over the next 30 years, while nuclear sees a small rise.

The net-zero scenario is similar in terms of the direction and order of trajectory but differs in terms of speed and magnitude. Use of coal falls substantially by around 80 percent by 2050, while oil declines by 50 percent. A significant proportion of oil will continue to be used in the petrochemical industry (currently around one-third of total consumption), which limits the reduction in

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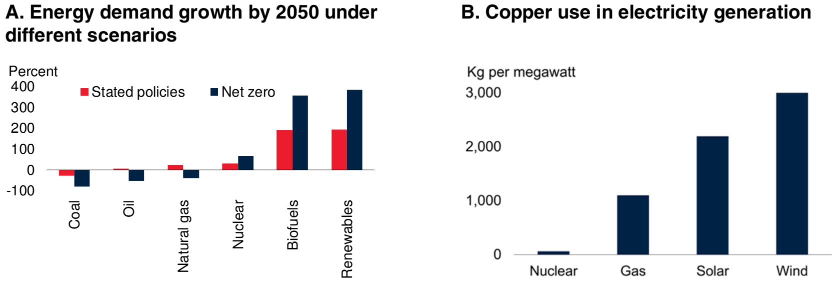
[c] The IEA's scenarios are broadly similar to those of BP and Shell. Differences chiefly pertain to the speed of the transition, which depend on policy choices and technological developments.

BOX 2.3 The energy transition: Causes and prospects *(continued)*

FIGURE B2.3.3 Speed and implications of the energy transition

The energy transition will result in significant changes in energy demand. Coal and crude oil will be the first to decline and see the sharpest falls, while natural gas may continue to increase. Renewables and biofuels will see the fastest growth, while nuclear will see modest gains. Demand for metals is likely to sharply increase as renewable technologies are very metals intensive.



Sources: Copper Alliance; International Energy Agency; World Bank (2017); World Bank.

A. Chart shows the change in energy demand for different fuels relative to their 2019 level under different scenarios from the IEA's *World Energy Outlook 2021* report.

B. Chart shows the amount of copper required to generate one megawatt of electricity using different generation methods.

use by 2050. Natural gas plateaus for the next decade before falling rapidly. For renewables, growth is expected to surge, rising more than four-fold over the next 30 years, with growth in solar power expected to be roughly double that of wind power. Similarly, biofuels are expected to rise five-fold by 2050. Nuclear is also expected to grow, albeit less rapidly, with a 70 percent increase.

Regardless of the scenario or forecaster, some commonalities hold. Coal is unlikely to see further increases and could start to see a rapid decline. Oil demand has broadly plateaued and will start to decline, albeit more slowly than coal, while natural gas is expected to see robust demand, at least in the next decade. Renewables and biofuels are set to see the fastest growth of any fuel, while the outlook for nuclear is less certain.

How will the energy transition affect demand for commodities?

Outlook for energy. Consumption of fossil fuels, especially coal, is expected to decline due to the increasing competitiveness of renewables. Increased take-up of electric vehicles will reduce oil demand. Further out, demand for fossil fuels will remain for industrial uses, such as petrochemicals and fertilizer production.

BOX 2.3 The energy transition: Causes and prospects *(continued)*

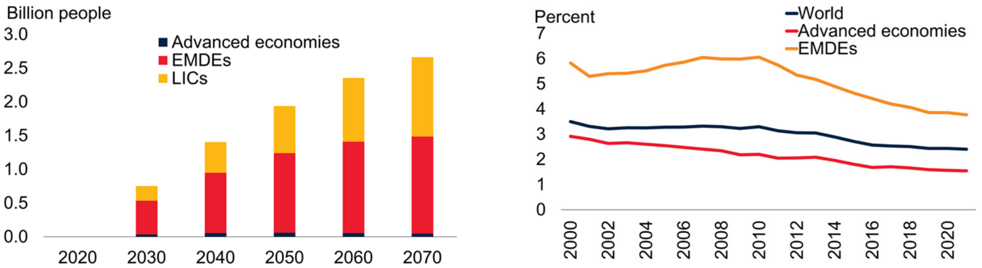
The impact of the energy transition on the production of fossil fuels, and consequently prices, is subject to greater uncertainty. The production of fossil fuels (especially natural gas and crude oil) requires significant investment in exploration and drilling simply to maintain current levels of production. Natural gas and oil wells can have high decline rates, particularly in the case of shale oil. Even if the demand for these fuels falls, substantial new investment will still be needed. As a result of ESG investing and shareholder activism, there has been a shift away from investment in new oil production by the oil majors. State-owned companies, however, have been under less pressure to diversify. Therefore, future production is likely to increasingly be accounted for by OPEC and its partners. The remaining producers will likely be those with the lowest cost of production, while higher-cost producers will be the first to curtail production.

Outlook for metals. In contrast to fossil fuels, demand for certain metals and minerals is likely to benefit from a shift to a zero-carbon future. Low-carbon-emission technology is typically more metals intensive than fossil fuel energy. The key metals needed for a low-carbon future are aluminum (including alumina and bauxite), chromium, cobalt, copper, iron ore and steel, lithium, manganese, molybdenum, nickel, platinum group metals, rare earth metals (which include cadmium, indium, and neodymium), silver, titanium, and zinc (World Bank 2017). At present, solar-generated electricity requires twice as much copper as natural gas, and wind requires three times as much (World Bank 2017). The same is true for electric vehicles. A traditional internal combustion engine car uses around 20kg of copper, while electric vehicles require more than four times as much (ICA 2017). The wiring of the EV charging infrastructure will also imply a boost in demand for both aluminum and copper.

Outlook for agriculture. For agricultural commodities, the main impact of the energy transition is likely to be through increased demand for biofuels. Projected scenarios anticipate a sharp increase in biofuel consumption wherever electricity is not a feasible energy substitute for crude oil. The main crops for biofuels are corn/maize (U.S.), sugarcane (Brazil), and vegetable oils such as canola and palm (European Union). Biofuels currently account for about 4 percent of total land allocated to food crops. However, rapid-transition scenarios anticipate a four-fold increase in production, which would represent a massive diversion of land from food crops. In addition, biofuels' net environmental benefits are limited by the energy required to produce and process the crops (Searchinger et al. 2008). To mitigate this pressure, a significant further increase in agricultural yields, or the development of advanced biofuels made from crop waste or algae, would be required. Climate change could also affect agricultural production. For example, temperature and precipitation changes affect crop yields and could render large areas unsuitable for cropping (Schmidhuber and Tubiello 2007).

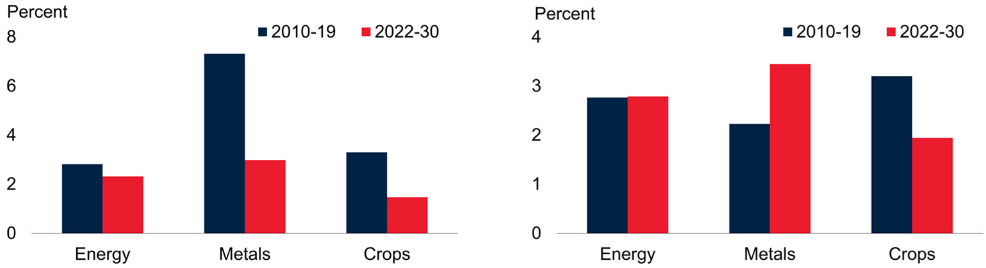
FIGURE 2.8 Future determinants of commodity demand

The global population is expected to continue to increase and will increasingly be driven by LICs, albeit at a slower pace than over the past half century. Similarly, global growth is expected to slow and be driven by EMDEs. Based on scenario estimates, demand for commodities in EMDEs is expected to slow, although metals demand growth will remain above energy and crops. Demand for metals excluding China is expected to increase, however.



A. Cumulative population growth forecasts

B. Long term growth forecasts



C. Scenario estimates of commodity demand growth in EMDEs

D. Scenario estimates of commodity demand growth in EMDEs excluding China

Sources: Consensus Economics; Organisation for Economic Co-operation and Development; United Nations; World Bank.

A. Chart shows cumulative increase in global population, by income levels, relative to 2020.

B. Chart shows 10-year-ahead consensus global growth forecasts.

C.D. Author estimates using United Nations population data, OECD growth rates, and estimated income elasticities of demand.

The simulation implies that growth in EMDE consumption for energy, metals, and crops slows over the next decade compared to 2010-19. The slowdown in metals is most pronounced, declining from an annual average of 7 percent to around 3 percent. However, this growth rate remains above that of energy and crops. The slowdown can be entirely attributed to China. If China is excluded, EMDE metal demand growth increases over the next decade as income elasticities of demand in the scenario stay above 1 in many EMDEs. For the other commodity groups, energy demand is expected to remain relatively constant, while crop consumption growth is estimated to halve.

The structural trends generated in the model simulation take explicit account only of income and population growth. Other factors, such as advances in global technology, shifts in consumer preferences, environmental concerns, and policies to encourage cleaner fuels, could trigger much more radical changes in the global use of some commodities. Of particular importance is the energy transition from fossil fuels toward low- or zero-carbon sources of energy. A technological transformation of this magnitude brings an unusually large and unpredictable component to long-run quantitative forecasts of the demand for commodities.

The direction of some changes, however, seems clear. The energy transition will lead to a reduction in the growth of demand for fossil fuels, particularly coal and crude oil, in favor of renewable energy sources (IEA 2021a). At some point, fossil fuel consumption will start to decline. In contrast, low-carbon energy systems are very intensive in their use of metals such as copper, nickel, cobalt, and lithium. Demand for these metals is likely to grow rapidly because of the transition, although their production capacity may pose potential bottlenecks for the transition (Boer, Pescatori, and Stuermer 2021; World Bank 2017). While agricultural commodities are likely to be less directly affected by the energy transition, a sharp increase in demand for biofuels could reduce the availability of resources to grow other crops, putting upward pressure on food prices. This would be an unwelcome development, given that the poorest households spend a high proportion of their income on food, and that climate change also poses a threat to food harvests.

Conclusions and policy implications

The past half-century has seen rapid growth in the consumption of most commodities. This growth is accounted for by population growth, income growth, and changes in the commodity intensity of output. Technological change, per capita income, and government policies have had important effects on commodity intensity.

Since 1970, global population has doubled, with growth concentrated mainly in EMDEs and LICs. Per capita income at the global level has more than doubled and has quadrupled among EMDEs. Thus, while global per capita consumption of commodities has leveled off over the past 20 years, consumption relative to GDP has declined. The decline in the commodity intensity of global output has been focused in energy and agricultural commodities. For metals, a similar downward trend in intensity was evident until about 2000, when the rapid industrialization of China brought a turnaround.

Econometric estimates of the income elasticities of demand for commodities indicate a causal pattern underlying these trends. The estimated elasticity, at median per capita income, is greater for metals than for energy, and lower for food than either. Demand for food has been almost entirely driven by population growth. Estimated income elasticities for all three commodity groups decline as incomes rise, providing support for the hypothesis that economic development involves a shift from material-intensive goods toward products with a higher value-added component, notably services.

EMDE demand for metals, and to a lesser extent energy, is expected to continue to grow over the next few decades, as many countries are still in a development phase associated with high income elasticities of demand. However, it is unlikely that EMDE commodity demand growth will repeat the growth rates experienced during the past two decades since income growth and industrialization policies in other countries are unlikely to replicate those of China. Further, while demand for energy will continue to grow, demand for fossil fuels is expected to decline, as energy will instead be provided by zero-carbon sources, such as renewables or nuclear energy.

The evolution of the drivers of commodity demand, together with likely changes resulting from the energy transition, will have significant implications in the years ahead. Aggregate commodity demand is expected to slow, reflecting the slowdown in income and population growth, and China's shift toward services. However, the outlook for different commodities varies substantially. Growth in demand for metals is likely to be higher than other commodities because of its high income elasticity of demand, as well as the energy transition. Energy demand should continue to grow, albeit at a slower rate. With the shift away from fossil fuels, however, demand for hydrocarbons will grow more slowly or decline, compared to the past 50 years. Demand growth for agricultural crops is likely to moderate in line with the slowdown in population growth. The slowing will likely be concentrated in basic foods such as grains, while demand for the more income-elastic foods, such as meat and dairy may see faster growth.

The emerging energy transition implies transformative substitutions among commodities, and underlays the robust growth projected for metal consumption. The switch to clean electric power implies a permanent increase in the demand for copper, nickel, cobalt, and lithium, and an eventual drop in the use of fossil fuels. With respect to agriculture, a slowdown in growth in demand for basic foods could be offset by an acceleration in the use of biofuels, the production of which is currently concentrated in a handful of countries, notably Brazil, the European Union, and the United States.

The expected growth in demand for most commodities is likely to be met over time by commensurate increases in productive capacity, as technology advancements induce innovation and increase possibilities for substitution (Schwerhoff and Stuermer 2019). However, the supply of minerals needed for renewable energy might encounter bottlenecks, especially in view of the long development period before new facilities come onstream. A key policy question in this regard is whether resources will be produced and consumed in an environmentally sustainable manner, given the substantial externalities. Local externalities may be relatively easy to address, since the approvals process typically concerns a single policy maker (such as a national or state government), although it can nevertheless be controversial, politically difficult, and time-consuming. Global externalities, with respect to climate change, plastic waste, water pollution, and other environmental challenges, extend beyond country jurisdictions. Action or inaction by one country affects other countries, for better or for worse. An effective program for environmentally sustainable production growth necessarily includes international measures to promote the beneficial spillovers of environmental protection.

TABLE 2.1 Parameter estimates

	Energy	Metals	Food
y_t	3.99*** (0.44)	9.08*** (0.42)	1.28*** (0.17)
y_t^2	-0.18*** (0.02)	-0.42*** (0.02)	-0.05*** (0.01)
p_t^{ENERGY}	0.22*** (0.02)	–	–
p_t^{METALS}	–	0.24*** (0.04)	–
p_t^{FOOD}	–	–	-0.07*** (0.01)
ρ	-0.08*** (0.01)	-0.18*** (0.02)	-0.27*** (0.02)
Key statistics			
No. observations	3195	2123	3799
No. Countries	62	42	77
Log-likelihood	5442	1778	4227

Note: The dependent variable is the logarithm of the specific commodity consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1%, 5%, and 10% level, respectively. Asymptotic standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

TABLE 2.2 Literature review of income elasticities

Authors and Year	Data/sample	Methodology	Results
Baffes, Kabundi, and Nagle (2021)	Three energy and six base metals, 63 countries, annual, 1965-2018	ARDL	At world median per capita income levels, 0.9 for metals and 0.7 for energy; elasticities decline as income rises.
Huntington, Barrios, and Arora (2017)	Energy, Price and income elasticity estimates of demand from 38 papers	Literature review	On average, 0.5 for oil and 0.9 for natural gas
Burke and Csereklyei (2016)	Energy, 132 countries, annual data, 1960-2010, energy	Panel OLS	Aggregate income elasticity is 0.7 for energy; it rises as income increases.
Csereklyei and Stern (2015)	Energy, 93 countries, annual data, 1971-2010	OLS	On average 0.6 to 0.8; as income rises, the rate of growth of energy use per capita declines.
Fouquet (2014)	Energy, UK, annual data, 1700-2000	VECM	As income rises, long run income elasticity for transport energy peaks at 3 before declining to 0.3.
Dahl (2012)	Energy, 240 gasoline studies (70 countries) and 60 diesel studies (55 countries).	Literature review	As per capita income increases, elasticity for gasoline falls from 1.26 to 0.66.
Joyeux and Ripple (2011)	Energy, 30 OECD and 26 non-OECD countries, annual data, 1973-2007, energy	ECM estimator	It is 1.1 for OECD countries and 0.9 for and for non-OECD countries.
Jakob, Haller and Marschinski (2012)	Energy, 30 EMDEs and 21 AEs, annual, 1971-2005	Difference-in-differences, panel data	Estimated at 0.63 for EMDEs and 0.18 for AEs.
Gately and Huntington (2002)	Energy and oil, 96 countries, OECD and non-OECD, annual, 1971-1997	Pooled demand equation, Koyck-lag model	Oil: 0.5 in OECD, 1.0 in non-OECD oil exporters, and 0.5 in other non-OECD.
Krichene (2002)	Crude oil and natural gas, World, annual, 1918-99	2SLS and ECM	Estimated at 0.6 for the full sample, it declines from 1918-73 to 1973-99.
Gately and Streifel (1997)	Eight oil products, 37 developing countries, annual, 1971-93	OLS	Estimated at 1.0 for most countries, and much higher for some oil exporters (e.g., 5.6 for Venezuela, 5.2 for Nigeria).
Bogmans et al (2020)	Energy, 127 countries, annual, 1850-2017	OLS	Supports Kuznets curve: elasticity increases at low-income levels, peaks at middle-income levels at around unity, and declines toward zero at high-income levels.
Bailliu et al. (2019)	Copper, 25 countries, annua, 1970-2015	PSTR	Elasticity of copper intensity to the investment share is fairly constant at around 0.5.

TABLE 2.2 Literature review of income elasticities (*continued*)

Authors and Year	Data/sample	Methodology	Results
Fernandez (2018a)	Steel and 6 base metals, world and 8 regions, annual, 1980-2015	OLS and SUR	Long-run income elasticities: 1.3 (nickel), 1.1 (aluminum and tin), 1.0 (steel), 0.9 (zinc), 0.7 (copper), and 0.5 (lead). By region: steel elasticities were all unity or higher; for base metals varied widely across regions.
Stuermer (2017)	Five base metals, 12 and 3 EMDEs, annual, 1840-2010	ARDL	Estimates (based on manufacturing output growth): 1.5 (aluminum), 0.9 (copper), 0.7 (zinc), 0.6 (tin), and 0.4 (lead).
Crompton (2015)	Steel, 26 OECD countries, annual, 1970-2012	Fixed effects panel model	Inverse-U relationship between steel consumption and GDP per capita. Estimates range from zero to 4.1 and are negatively related to the country's GDP.
Wårrel (2014)	Steel, 61 countries, annual, 1970-2011	OLS, panel time series	Intensity-of-use holds for countries real per capita GDP (2011 terms) between US$ 6,000 and 30,000 US. The turning point occurs at $19,000. A reverse relationship is found among high-income countries.
Guzman, Nashiyama, and Tilton (2005)	Copper, Japan, annual, 1960 -2000	Various forms of time trend models	Intensity-of-use , with the intensity of copper use in Japan increased until GDP per capita reached $18,285 in 1969; it declined since then.
Tcha and Takashina (2002)	Steel and 6 base metals, 1960-93 (world) and 1973-93 (7 regions)	Divisia moments	Estimates range 0.6 (lead) to 1.3 (nickel).
Valin et al. (2014)	Agricultural commodities, 10 economic models	Literature review (models)	Median income elasticities for rice and wheat estimated to be close to 0.1. First and third quartile range of estimates range from 0 to 0.2.

Note: ARDL (Autoregressive Distributed Lag); OLS (Ordinary Least Squares); SUR (Seemingly Unrelated Regressions); ECM (Error-Correction Model); 2SLS (Two-Stage Least Squares); VECM (Vector Error-Correction Model)

TABLE 2.3 Literature review of urbanization and commodity demand

Author(s)	Data	Main topic	Main findings
Baffes, Kabundi, and Nagle (2021)	Panel of 63 advanced economies and EMDEs, 1965-2017	Aggregate energy and metal consumption	Urbanization has a positive effect on energy and metal consumption (positive on coal and natural gas consumption but negative effect on oil).
Dasgupta, Lall, and Wheeler (2021)	1,236 cities in 138 countries, 2014-2020	CO_2 emissions	Urban areas with higher population density have higher CO_2 emissions at very low levels of per capita income, but lower CO_2 emissions at higher income levels (above $1,000 per capita).
Hovhannisyan and Devadoss (2020)	Panel data on consumer food expenditure in China, 2005-12	Food consumption	Urbanization has reduced demand for grains, vegetables, and fats and oils while increasing demand for meats, fruit, and eggs.
Pandey et al. (2020)	Consumer expenditure survey data covering 124 food commodities at the household, district, and state level in India	Food consumption	Although urbanization leads to varied diets, most of the change in food consumption patterns between urban and rural areas is due to income, not urbanization.
Larson and Yezer (2015)	Theoretical model calibrated with empirical estimates of model parameters with calibration target of 10 U.S. cities	Energy use from transport and dwellings	A doubling in urban population leads to a 2.6 percent reduction in energy use from transport and dwelling use.
Salim and Shafiei (2014)	Panel of 29 OECD countries, 1980-2011	Aggregate energy use (renewable and non-renewable)	Urbanization has a positive effect on non-renewable energy use (due to changing consumer needs and increased transport demand) but little effect on renewable energy use.
Sadorsky (2013)	Unbalanced panel of 76 developing countries, 1980-2010	Energy intensity	Urbanization has an insignificant effect on energy use in most versions of the model; income is a statistically significant negative driver of energy intensity.
Brounen, Kok, and Quigley (2012)	Sample of 300,000 households in the Netherlands, 2008-09	Energy use from dwellings	Apartments and row homes had significantly lower energy consumption than detached and semi-detached homes. An additional person per household reduced per capita natural gas and electricity consumption by 26 percent and 18 percent, respectively.
Morikawa (2012)	Microdata covering up to 66,000 service sector firms in Japan, 2007-08	Energy use by service sector	The efficiency of energy consumption in service companies is higher in densely populated cities. Energy efficiency increases by 12 percent when density doubles.
Poumanyvong and Kaneko (2010)	Panel dataset of 92 countries (low- medium- and high-income), 1975-2005	Aggregate energy consumption	Urbanization results in lower energy use in low-income countries (perhaps due to switching from inefficient to efficient fuels). Urbanization leads to increased energy use in middle- and high-income countries.

TABLE 2.3 Literature review of urbanization and commodity demand (*continued*)

Author(s)	Data	Main topic	Main findings
Poumanyvong, Kaneko, and Dhakal (2012)	Panel dataset of 92 countries (low- medium- and high-income), 1975-2005	Energy use from transport	Urbanization leads to more energy use in transport for all income groups, especially high-income countries.
Glaeser and Kahn (2010)	Single-year survey and census data for U.S. metropolitan areas	GHG emissions from energy use	Higher-density cities have lower emissions than low-density cities. This is due to lower emissions from driving and electricity, while emissions from public transport and heating are higher.
Brownstone and Golob (2009)	Single-year survey data for California, U.S.	Energy use from transport	Lower-density households travel more and consume more fuel, both a result of increased travel time, as well as self-selection of less efficient cars.
Liu (2009)	China, 1978-2008	Aggregate energy consumption	Urbanization has a positive effect on energy consumption – much smaller than that of income and decreasing over time.
Mishra (2009)	Nine Pacific island countries, 1980-2005	Aggregate energy consumption	In aggregate, a 1 percent increase in the rate of urbanization generates a 2.4 percent increase in energy consumption. However, the effect was positive in only 4 of the 9 countries (negative in 1, and insignificant in the other).
York (2007)	Panel of 14 EU countries, 1960-2000	Aggregate energy consumption	Urbanization leads to more energy consumption.
Liddle (2004)	Panel data, 23 OECD countries, 1960-2000	Energy consumption by transport	Highly urbanized and more densely populated countries have lower personal transport consumption.
Lariviere and Lafrance (1999)	Single-year data on electricity consumption, 45 cities in Canada	Electricity consumption	High-density cities use slightly less electricity than lower-density ones.
Parikh and Shukla (1995)	Panel dataset of 72 countries, 1965-87	Aggregate energy consumption	A 1 percent rise in urbanization leads to a 0.28 percent rise in energy use. This is driven by transport and is attributed to greater intra-urban commuting and congestion.

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