CHAPTER 4

Carbon neutrality concept and progress

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# 1 Introduction

Sufficient scientific evidence now shows that Earth’s temperature is warmer than before. The temperature of the planet (global warming) is becoming s source of climate change that is estimated to have negative consequences for all living beings ([Sovacool and Griffiths, 2020](#_bookmark56)). Climate change, if it keeps moving in the direction in which it is heading now, will have severe consequences for anything and everything that exists on this planet. This is not a man-made story; rather, the argument is established upon the data collected by international organizations such as United Nations’ Intergovernmental Panel on Climate Change, Environmental Protection Agency, and NASA, among others. Data on global warming have been gathered across multiple time periods and analyzed for a very long time to arrive at the conclusion of severe and unpleasant consequences for everyone and everything on the planet. Excessive carbon dioxide emis- sions is the main contributing factor of global warming. However, it is not only carbon dioxide that causes global warming—many other gases are harmful to the climate, such as carbon dioxide, methane, and nitrous oxide, as well as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. This is not an exhaustive list, but for now, think of greenhouse gases as a catch-all term for the harmful substances we are pumping into the atmo- sphere. Since carbon dioxide has the most significant share among harmful gases, academic and nonacademic researchers study carbon dioxide more than other gases.

Climate change has become a major global challenge for sustainability of all living beings. It has become global issue, hence it needs global attention to remove or at least minimize its impact on humanity. Therefore, it becomes pertinent to divide this task into two phases:

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1. identification of sources and/or causes of green gas emissions and
2. finding sustainable solutions to the climate change issue.

In terms of identification, sources of adversity in climate have been identified and they are named as harmful gases (green gases), with carbon dioxide being the major contributor. Modern factories are major sources of carbon dioxide emissions. Closing factories would shut down the entire economic activities of modern times and give rise to a number of new issues including un-addressable differences in supply and demand of various essential items. Therefore, we need sustainable and doable solutions to mitigate the impact of carbon emissions. The most popular term used for addressing the issue is “carbon neutrality.” This refers to offsetting the generated carbon dioxide (CO2) through carbon capture, storage, and conversion within a certain period of time, so as to achieve “zero emissions” of greenhouse gases.

The idea of spreading the concept of carbon neutrality will increase the awareness of significance of having it and will assist in decreasing the con- centration of air pollutants. Awareness alone does not meet the aim of car- bon neutrality; definite and doable paths of attaining it need to be established. The approach of attaining it need to be multifaceted, including use of innovative technology, developing methods of low carbon emissions in production without compromising productivity levels, and financial sup- port to achieve these objectives smoothly. [Attahiru et al. (2019)](#_bookmark5) highlighted the application of carbon-neutral materials in the construction of roads and highways, using the phrase “green roads and highways.” [Sovacool and Grif-](#_bookmark56) [fiths (2020)](#_bookmark56), [Lee et al. (2021)](#_bookmark32), [Carvalho et al. (2020)](#_bookmark11), and [Ren et al. (2021a,](#_bookmark48) [b)](#_bookmark48) also reviewed the low carbon energy transition and use of low-carbon technologies.

# 2 Carbon neutrality—Global pledges and practices

As part of this, UN Climate Change launched Climate Neutral Now in 2015 in order to encourage stakeholders around the world to work toward net zero emissions and a climate neutral world. This would see a world where global emissions are in balance with what is naturally absorbed in “sinks” such as forests and oceans. While the aim is to have a “climate neutral” world by 2050, Climate Neutral Now focuses on the need to take action now in order to reach that target. A carbon neutral world has become a global goal and more than 120 countries have proposed carbon neutrality targets to achieve by 2050. A few countries have reached their carbon neutrality tar- gets, such as Bhutan (2018) and Suriname (2014). Owing to the significance

of the need of carbon neutrality, many countries have pledged to attain the targets soon, such as Uruguay by 2030, Finland by 2035, Iceland by 2040, and Sweden by 2045. France, Costa Rica, Ireland, South Africa, the United Kingdom, South Korea, and Singapore have all set the target of reaching carbon neutrality by 2050. Much of the world community seems to have reached a consensus on carbon neutrality targets, and other countries will soon join these efforts to deal with the global issue of climate change due to increases in carbon emissions. Countries that are the main contributors of global CO2 emissions have set their direction and have formulated pol- icies to reduce global CO2 emissions. China is currently the leading carbon emitter in the world, accounting for 28% of global CO2 emissions in 2019, and this rose to 32% in 2020. However, the China government has a strong resolution to reduce their carbon footprint, hence their current practices have reduced the contribution of carbon emissions from China.

China has made remarkable achievements in addressing climate change. The intensity of greenhouse gas emissions has been effectively controlled. The carbon emissions amount in the evironment is reduced by 18.2% from 2015 and 48.1% compared to 2005 record. The Chinese government has taken a series of concrete measures by setting low carbon emissions targets province-wise. Cities with peak carbon emissions have put in practice for carbon neutrality. The local administrative bodies have set a target of switch- ing to low carbon energy sources to limit the use of sources that cause more carbon emissions. Shanghai is a typical example; it keeps pace with its carbon neutral goal by adjusting its energy structure, supplying clean energy, recy- cling garbage, reducing building energy consumption, and so on. Due to the importance of carbon neutrality, the European Union (EU) announced European Green Deal in Brussels regarding a new climate change policy. This policy has the high aim to attain net zero greenhouse gas emissions. This policy would lower the EU’s carbon emissions by 40% by 2030, fur- thermore, it would be reduced to 80% by 2050. Following China, the EU’s low carbon emissions targets are set out city-wise. Approximately 78% of cities have carbon emissions reduction targets and the rest have the ambition to realize carbon neutrality. However, the EU still faces various challenges in achieving carbon neutrality, including significant capital expenditures, chal- lenging technological breakthroughs, and social equity. Furthermore, because China and the EU are major strategic partners in global climate pol- icy, they should work together to attain carbon neutrality ([Cai et al., 2021](#_bookmark7)). In 2018, the Danish government announced a plan to develop a “carbon- neutral society” by 2050, which included a prohibition on the sale of new

petrol and diesel automobiles and a push for the widespread use of electric vehicles. To keep up with global carbon neutral development, Copenhagen advocated a range of low-carbon initiatives, such as boosting construction efficiency, constructing energy-efficient buildings, expanding the use of solar cells, supporting technical innovation, and developing smart cities. In the transportation sector, it promoted green travel, which includes walk- ing, biking, and using the bus, using clean fuel, and managing traffic wisely. Copenhagen proposed biomass energy and waste recycling into energy in the area of manufacturing capacity.

Following China’s 2060 carbon-neutral target, Japan pledged to achieve carbon neutrality by 2050. To that end, Japan will alter its coal power strat- egy radically and enhance research in critical technological areas such as renewable energy technology and the use of carbon cycle technology. Korea has likewise proposed a carbon-neutral target. South Korean President Moon Jae-in has pledged to become carbon neutral by 2050 and to shoulder worldwide responsibilities for combating climate change. South Korea, as one of the world’s most fossil-fuel-dependent economies, will attain carbon neutrality gradually by utilizing more renewable energy instead of traditional fuel, investing in clean energy, electric cars, and environmental infrastruc- ture. Although India has set a carbon-neutral objective for 2050, the coun- try’s power sector, heavy industry, transportation, and other sectors continue to rely on coal, and the country’s progress toward a clean energy economy is glacial. It is still unclear if India’s carbon-neutral objective can be met. Biden is a vocal supporter of taking action against climate change and global warming. The Biden Plan for a Clean Energy Revolution and Envi- ronmental Justice, released during the campaign, advocated for a “carbon- free electrical society” through the use of renewable energy by 2035, as well as “carbon neutrality and a 100% clean energy economy by 2050” ([Wu et al.,](#_bookmark65) [2022](#_bookmark65)). The United States’ mixed views about climate change, however, make it more challenging to meet its carbon neutral target ([Wu et al., 2022](#_bookmark65)). The UK exhibits excellent responsibility regarding climate governance.

The goal of the Paris Agreement, which the UK signed up to in 2015 along with 178 other nations, is to keep the average global temperature rise from preindustrial levels to 1.5°C. In the updated “Climate Change Act,” which was passed in June 2019, the United Kingdom affirmed unequivocally that it would become carbon neutral by 2050. The UK is the first industrialized nation to codify a carbon neutrality aim into legislation and to implement carbon neutrality measures. The British Standards Institute (BSI) published the first carbon neutral specification (PAS 2060) in the world ([Koondhar](#_bookmark30)

[et al., 2021](#_bookmark30)). Additionally, the British civil aviation sector unveiled a plan to become carbon neutral by 2050. The UK published The Ten Point Plan for a Green Industrial Revolution in November 2020. London, the capital of the UK, pledged to cut carbon emissions by 80% by 2050 while establishing clear low-carbon standards for the building, transportation, and other industries. Globally, the movement toward carbon neutrality has become unstop- pable. Some academics examined the trend’s characteristics and suggested actions for China. Major emitters like India should set credible carbon- neutral objectives as soon as feasible; the European Union and other wealth- ier nations should take the lead in the global transition to carbon neutrality; to achieve its own carbon neutral aim, China should study successful nations’ advanced carbon neutrality experiences. According to [Wu et al. (2021)](#_bookmark64), China should develop its own unique emissions reduction strategies and enhance scientific and technology research in this area. Businesses must also take the initiative to reform and occupy the market in order to keep up with other nations in the development of carbon neutrality. Furthermore, China is vying for dominance in the global control of environment with the main powers represented by the USA and the EU. As a result, China must create a rational and fact-based plan for achieving carbon neutrality, advance ecolog- ical technology, foster more international communication and collabora- tion, and work to go beyond being a participant and contributor to being

a leader in the field.

# Approaches and progress toward carbon neutrality

Climate change may be lessened by stepping up efforts to become carbon neutral. Exploring the approaches to a low-carbon civilization is therefore very important. The Institute of Climate Change and Sustainable Develop- ment of Tsinghua University’s Research on China’s Long-Term Low- Carbon Development Strategy and Transformation Path ([Zhang et al.,](#_bookmark73) [2021a, b](#_bookmark73)) outlines the pathways for China’s low-carbon transition, including industrial restructuring, energy conservation, efficiency improvement, clean energy utilizations, development of circular economy, and others. [Wang](#_bookmark62) [et al. (2021)](#_bookmark62) stated that China must follow four main approaches in order to become carbon neutral: energy structure transformation, model upgrad- ing, energy efficiency improvement, and carbon capture and storage (CCS). The Research Report on Air Quality Standardization and Carbon Peak Pathways in Typical Cities, which used typical Chinese cities as examples to explore the path of coordinated emissions reduction among cities and

serve as a guide for the attainment of carbon neutrality, was completed by Tsinghua University ([Tian and You, 2019](#_bookmark59)). The routes to carbon neutrality were loosely separated into three stages by [Lin (2020)](#_bookmark35). The emphasis varies at each step. The first phase (2020–30) will concentrate on modifying the energy structure to reach the carbon peak. Phase 2 (2030–45) will signifi- cantly increase the use of carbon capture, utilization, and storage (CCUS) technology, cut carbon emissions quickly, and use renewable energy. The main objective of Phase 3 (2045–60) is to achieve carbon neutrality through decarbonization, the use of renewable energy, and the use of carbon sink technologies. Similar to this, [Wang and Zhang (2020)](#_bookmark61) separated the channels into the social, technological, and emissions paths. In contrast to Lin’s the- ory, there is a second plateau of transition following the peak in 2030–35. Additionally, the technological path denotes the path toward net zero emis- sions, whereas the social path mostly relates to interactions between govern- ment, businesses, and people. Studies have also used quantitative analysis to examine the routes to carbon neutrality. For instance, [Hongbo et al. (2021)](#_bookmark22) created eight comprehensive assessment models to investigate the short- and long-term pathways for China’s natural gas sector to achieve carbon neutral- ity. A thorough energy-economy-environment system model was devel- oped by [Wang et al. (2021)](#_bookmark62), who also examined China’s low-carbon options in light of the 1.5°C objective. On the basis of China’s high spatial resolution emissions grid information, [Cai et al. (2021)](#_bookmark7) established China’s CO2 emissions path for 2020–60 under the carbon neutrality aim. To research China’s pathways to carbon neutrality (including energy systems, CCS technologies, and carbon sinks), [Yu et al. (2021)](#_bookmark71) created a top-down comprehensive evaluation model and examined the role of each pathway in various contexts. Achieving the goal of carbon neutrality is also influenced positively or negatively by environmental research and development (R&D) ([Khan and Ghouri, 2022a](#_bookmark26)), green innovation ([Ghouri et al., 2020](#_bookmark20)), environ- mental policy, trade openness ([Ghouri and Haq, 2018](#_bookmark19)), financial develop- ment ([Khan et al., 2020a](#_bookmark28)), environmental taxes, low carbon policies ([Khan and Ghouri, 2022b](#_bookmark27)), income inequality, public-private investment ([Khan et al., 2020b](#_bookmark29)), FDI ([Khan et al., 2020a](#_bookmark28)), and political risk. Approaches are discussed separately as follows.

# Energy

Today, several nations’ energy structures still rely mostly on the usage of coal. The first step toward a world without carbon emissions is changing

the energy structure and switching from coal usage to clean energy. The government will speed up the energy transformation toward carbon neutral- ity through market mechanisms over the long term, notwithstanding the fact that policies to reduce coal usage may temporarily lower social welfare levels. To show the many parts of the energy path, the following will be sep- arated into renewable energy and electricity.

* + 1. *Renewable energy*

Renewable new energy has gained increasing public attention as a result of the quick development and broad usage of solar energy, wind energy, hydropower, and many other new energy sources. In the near future, new energy will be the key to achieving carbon neutrality; nevertheless, changing current energy habits is also very important. Some researchers have carried out studies on the use of renewable energy. For instance, [An et al.](#_bookmark3) [(2015)](#_bookmark3) discovered that ethanol is an excellent carbon-neutral fuel and that ethanol-based direct ethanol fuel cells may dramatically increase perfor- mance and efficiency while drastically lowering carbon emissions. Ammonia may be utilized as a raw material to create direct ammonia fuel cells, which might have positive effects on environment and the transportation industry. According to [Koondhar et al. (2021)](#_bookmark30), using bioenergy also helps the world achieve its carbon-neutral objective. According to a study by [Song et al.](#_bookmark55) [(2022)](#_bookmark55), power systems and hydrogen systems will take center stage in the development of carbon-neutral energy supply systems. The contribution of solar energy to carbon neutralization was researched by [Wu et al.](#_bookmark64) [(2021)](#_bookmark64). Their results indicated that when compared to coal power, solar can reduce both energy usage and carbon emissions by half. According to [Jing et al. (2021)](#_bookmark24), wind power is another efficient method. [Zhao and](#_bookmark74) [You (2021)](#_bookmark74) investigated the capacity of New York’s electricity and space heating sectors for decarbonization using a bottom-up energy transition optimization model. They estimated that by 2050, geothermal technology and air-source heat pumps will provide 47% and 41% of the heat demands, respectively, while offshore wind energy will provide 66% of the power need and emerge as the major source of electricity. [Qia (2021)](#_bookmark47) utilized the systematic dynamics model to confirm the capabilities of wind power to reduce carbon emissions. A hybrid energy system also makes it easier to become carbon neutral. A hybrid energy system created by [Tian and](#_bookmark59) [You (2019)](#_bookmark59) combines deep water cooling, biomass heating, and geothermal power generation to meet heating and cooling demands while also lowering carbon emissions. An integrated energy system with a hydrogen natural gas

hybrid energy system was introduced by [Tan et al. (2021)](#_bookmark57). Energy conser- vation is another crucial step toward being carbon neutral, since it may reduce the need for coal while lowering operating costs. The transition to carbon-neutral energy, however, will confront enormous obstacles that call for active participation and collaboration from all sectors at the local, national, and even global levels. Furthermore, government participation cannot be disregarded. According to [Wang et al. (2021)](#_bookmark62), analysis from the geosciences, choosing new energy sites wisely and sensibly, creating tech- nologies for exploration and exploitation, and coordinating key geological departments are all necessary for the realization of energy that is carbon- neutral electrical power. The achievement of carbon neutrality aim is accel- erated by renewable power ([Liu, 2019](#_bookmark37)).

* + 1. *Electricity*

According to the report “China Zero-Carbon Electricity Growth in the 2020s: A Vital Step Toward Carbon Neutrality” ([Cao et al., 2021](#_bookmark9)), as electrification advances, China’s electricity demand will increase to 10–12 trillion kilowatt-hours by 2030 and almost entirely electrify by 2050, using twice as much electricity as at present. The idea of carbon neutrality has sped up the process of making electricity carbon-free and advanced higher standards for emissions reduction in the power sec- tor trend of electricity quantitatively. By using biomass direct combus- tion/gasification power generation, biomass coupled power generation, and biomass and carbon capture and storage technology as examples, [Li et al. (2021)](#_bookmark34) combined biomass energy with electricity and investigated the viability of electric power in promoting carbon neutralization process. According to [Zhang and Hanaoka (2021)](#_bookmark72), the adoption of electric vehi- cles will reduce carbon emissions, resulting in the transportation industry being carbon neutral.

# Technological advancements

Carbon emissions reduction and technological advancement are strongly intertwined. The impact of technological advancement on achieving carbon neutrality was extensively researched. This section divides the low-carbon technological approaches into CCS, CCUS, and BECCS, and carbon sink technology.

* + 1. *Carbon capture and storage (CCS), carbon capture, utilization, and storage (CCUS), and bioenergy with carbon capture*

*and storage (BECCS)*

The term carbon capture and storage (CCS) describes the procedure of removing CO2 from associated emission sources, transferring it to the stor- age location, and prolonged atmospheric isolation. In order to increase net thermal efficiency and lower carbon emissions significantly, [Prabu and Geeta](#_bookmark46) [(2015)](#_bookmark46) presented an underground coal gasification system that employs CO2 as a gasification medium in conjunction with CCS technology. The role of bioenergy-based CCS in reaching carbon neutrality in the European steel sector was explored by [Mandova et al. (2019)](#_bookmark39). They discovered that CCS can dramatically lower the amount of carbon emissions produced by European steel factories; however, it is not widely accepted and has a finite amount of carbon storage space. A linear programming model was cre- ated by [Ding et al. (2020)](#_bookmark16) to assess the financial impact of CCS on China’s steel sector. They found that even if this technique cannot be implemented on a large scale in the near future, it offers significant long-term economic and environmental benefits. On the basis of the integration of a bottom-up technology-section model and a computable general equilibrium model, [Ren et al. (2021a, b)](#_bookmark48) also investigated the viability of CCS in China’s iron and steel sector.

Contrary to CCS, CCUS does more than store CO2. Additionally, it cleans CO2 before reusing it in a new manufacturing process. One of the doable methods to attain carbon neutrality is CCUS, which, in contrast to CCS, considers both economic and environmental advantages. The Global Comprehensive Assessment Model (GCAM-China) was used by [Yu et al. (2021)](#_bookmark71) to examine the specific status of CCUS in 31 Chinese prov- inces. They discovered that CCUS has gained popularity across a number of provinces’ industrial and electric power sectors and that it is crucial in regions with significant carbon storage potential, such as Shandong, Inner Mongolia, and Hebei. Through the use of the learning curve model, [Wei](#_bookmark63) [et al. (2021)](#_bookmark63) discovered that CCUS has greater competitive advantages than renewable energy.

BECCS technology, in contrast to CCS and CCUS systems, mixes car- bon capture and storage with bioenergy. By removing carbon dioxide from the atmosphere, it helps to reduce greenhouse gas emissions and achieve car- bon neutrality. A crucial technology for the Intergovernmental Panel on Climate Change (IPCC)’s 2 and 1.5°C objectives, BECCS might also lower the costs of achieving carbon neutrality ([Chao et al., 2019](#_bookmark12)). As a result,

numerous businesses are drawn to this technology in order to cut their car- bon emissions. According to analysis by [Rong et al. (2021)](#_bookmark49) of the interaction between China’s carbon market trading and CCUS, carbon prices can sig- nificantly aid CCUS growth. [Wang et al. (2021)](#_bookmark62) investigated the coopera- tive growth of CCUS and hydrogen energy, and discovered that carbon emissions from the creation of hydrogen may be captured and used again by CCUS. Even though CCS and CCUS are essential for reaching zero car- bon emissions, these technologies are still in their infancy. The constant requirement for corresponding countermeasures is vital. Additionally, [Zhang et al. (2021a, b)](#_bookmark73) analyzed the existing problems with China’s CCUS development and suggested solutions.

* + 1. *Carbon sinks*

The term “carbon sink” describes the process of absorbing atmospheric car- bon dioxide through reforestation, vegetation restoration, and other methods in order to lower the atmospheric concentration of greenhouse gases. It comprises of ocean and terrestrial carbon sinks in general. Forest carbon sinks, agricultural carbon sinks, and other terrestrial carbon sinks are examples. In addition to being economically valuable, forest carbon sinks can hasten the achievement of the aim for reducing carbon emissions. [Li](#_bookmark34) [et al. (2021)](#_bookmark34) studied the ability of Central Asia as a carbon sink in recent years and revealed a decreasing trend. Increased human activity and drought will accelerate the declining trend. The carbon sink capability of Chinese forest vegetation was examined by [Zhang et al. (2021a, b)](#_bookmark73). [Lin and Ge (2020)](#_bookmark36) looked at the relationship between educational freedom and the forest’s role as a carbon sink. Ocean carbon sinks also serve a crucial, essential function in lowering the atmospheric concentration of greenhouse gases. The capacity of China’s marine carbon sink was investigated by [Song et al. (2020)](#_bookmark54). Zhe- jiang, Fujian, and Shandong are the provinces with the highest marine car- bon sink values, while Hebei, Tianjin, and Shanghai have the lowest. Regarding the technological approach, the majority of the recent research has been focused on CCS, CCUS, BECCS, and carbon sink technologies. However, there are many more negative emission technologies (these tech- nologies remove greenhouse gases, e.g., carbon dioxide) out there that need to be investigated. There is very little quantitative study of the viability and growth potential of these technologies. In addition, studies on the costs asso- ciated with the marketing and usage of the aforementioned technologies are currently limited, and should be looked into in the future.

# Social norms

The social route shows the low-carbon actions taken by citizens, families, and businesses to support the achievement of carbon neutral goals. Accord- ing to [Deng and Wang (2020)](#_bookmark15), adopting energy labels, redesigning informa- tion channels, and enhancing individual education and manners may all help raise household knowledge of low-carbon consumption and encourage low-carbon consumption behavior. The structural equation model was used by [Yin and Shi (2021)](#_bookmark69) to investigate the low-carbon consumption patterns of Chinese citizens. They discovered that whereas network size indirectly affects low-carbon behaviors through social norms, information intensity directly promotes low-carbon consumption behavior among Chinese peo- ple. The social road will be divided into two categories in this section: con- sumer willingness to pay for carbon neutral and social advocacy actions.

* + 1. *Propaganda for social causes*

Numerous Chinese provinces and towns have conducted a number of ini- tiatives to spread the word about the idea of carbon neutrality. For instance, on May 20, 2020, Shanghai hosted the official launch of the [E60 Carbon](#_bookmark17) [Neutral Pioneer Project for Millions of Teenagers (2021)](#_bookmark17). Through subject research and science practice activities, this project aims to help millions of young people develop low-carbon consumption and lifestyle habits. The “Walk to Get Carbon Coins” initiative was started in the Chinese province of Guangdong on August 25, 2021. By participating in this activity, locals may obtain low-carbon coins and learn more about carbon neutrality. Working on technologies fundamental to carbon neutrality is its goal. Through energy changes, other colleges in other nations joined the carbon-neutral initiatives. Although its carbon-reduction initiatives, such as deploying campus electric vehicles, resulted in an increase of 2.4% in energy prices, they have reduced greenhouse gas emissions to varied degrees.

* + 1. *Willingness of consumers to pay for carbon neutrality*

In order to achieve carbon neutrality, consumer actions cannot be disre- garded. Therefore, a key component of research regarding carbon neutrality is customer willingness to pay. Studies in this field concentrate on the vari- ables that influence people’s willingness to pay toward carbon neutrality. First, different nations or areas may have different levels of willingness to pay toward carbon neutrality. On the propensity of airline passengers to pay for carbon offset projects, tourists from the UK and Europe are more

likely to do so than those from Asia. Air travelers are more inclined to sup- port local carbon offset programs than global ones. Second, other elements including gender, educational attainment, social standing, income, and other characteristics, may also impact how ready people are to pay for carbon neutrality. In Australia, female air passengers are more likely than male ones to contribute money to carbon neutral projects. People’s willingness to pay for carbon neutrality is negatively associated with academic achievement and personality, but favorably correlated with monthly income and social status. Education, income, and understanding of climate change concerns have a considerable influence on one’s willingness to pay for carbon offsetting.

# Operations and management

Low-carbon policies and low-carbon economic measures are generally used to reduce carbon emissions in terms of low-carbon operations and management.

* + 1. *Carbon-reducing measures*

Carbon quota policies, low-carbon pilot city policies, and other pertinent policies are all included in low-carbon policies. Carbon quota denotes the requirement to achieve the set regulations for reducing greenhouse gas emis- sions. Carbon quota policies have been proven to be a successful strategy for achieving low carbon logistics by [Li et al. (2020a, b)](#_bookmark33). Regarding low-carbon pilot city policies, [Yu and Zhang (2021)](#_bookmark70) found that they can greatly improve carbon emissions’ efficiency. The implementation of a low-carbon pilot city program might raise the total factor (TFP) of businesses. Carbon trading pilot strategy might improve China’s industry’s competitiveness on the global market by advancing low-carbon technologies. Additionally, perti- nent industrial policy, innovation policy, and transportation policy all make various contributions to low-carbon operations and management. Hierar- chical instruments are the most effective policies, according to [Ma et al.](#_bookmark38) [(2021a, b)](#_bookmark38), who studied the effects of several types of policy instruments on China’s carbon reduction means for a low-carbon economy. Carbon tax and emission trading systems are components of a low-carbon economy. A levy on carbon dioxide emissions is referred to as a “carbon tax.” [Zhang](#_bookmark73) [et al. (2021a, b)](#_bookmark73) and [Carroll and Stevens (2021)](#_bookmark10) have shown that carbon tax mechanisms can reduce carbon emissions. Carbon tax also helps to eco- nomic growth and decreases energy consumption, respectively, based on the CGE model. [Povitkina et al. (2021)](#_bookmark45) nonetheless made the argument that applying carbon taxes is unjust because of high petrol costs and low public

confidence in the government. In terms of a market mechanism, “The Tokyo Protocol in 1997 established a system for selling carbon emissions. It treats the rights to emit carbon dioxide as a commodity, resulting in the trading of these rights. On condition that the cap on emissions set by legislation governing carbon emissions trading is not exceeded, it permits businesses to use the decreased carbon emissions to consume or trade energy both domestically and abroad. China, the top carbon emitter in the world, published “Measures for the Administration of National Carbon Emissions Trading,” which, through laws, can encourage more funding to go to carbon-neutral projects. The reduction of carbon emissions can be aided considerably by carbon emissions trading schemes.

# Carbon neutrality issues

Continuous efforts have been undertaken in the domains of forestry, avia- tion, building, finance, transportation, etc. to attain the aim of carbon neu- trality since the idea has been gradually advanced on a worldwide scale. Some brief descriptions of these issues are given here.

# Forestry

The present research is categorized in this area into four groups:

* + - * forest carbon storage;
      * forest carbon sink;
      * forest management; and
      * barriers to initiatives that would neutralize forest carbon.

The estimation of forest carbon storage and the influences on forest carbon storage make up the current study on this topic. The overall carbon storage capacity in China’s three largest forests was determined by [Xu et al. (2020)](#_bookmark66). The potential of each forest to store carbon was shown to have increased steadily between 2013 and 2030. During the course of 70 years, China’s overall carbon storage grew by 106.46%, while the carbon storage inside for- est stands increased by 94.74%. According to studies on the variables influencing carbon storage, household involvement in forest management and public audits can increase carbon storage capacity considerably. [Li](#_bookmark33) [et al. (2020a, b)](#_bookmark33) used multiple regression models to investigate the effects of forest age, climate, biodiversity, and biomass on the storage of carbon in the forest.

The process through which forest plants absorb CO2 from the sky and fix it in vegetation or soil, lowering the concentration of greenhouse gases in

the atmosphere, is referred to as a forest carbon sink. The computation of forest carbon sink capacity, its affecting elements, and the assessment of the value of forest carbon sinks are the primary areas of interest in pertinent research. For instance, [Xue et al. (2017)](#_bookmark67) measured the provincial and urban forest carbon sinks in China using the forest accumulation expansion approach. The findings demonstrated that China’s capability as a forest car- bon sink increased from 1988 to 2013, with clear regional variations. After examining two tropical forests in West Bengal and India, [Karmakar et al.](#_bookmark25) [(2019)](#_bookmark25) noted that the ability for carbon sequestration varies across tree spe- cies of different kinds and sizes. Similar to this, [Shu et al. (2019)](#_bookmark53) investigated the ability of subalpine primeval fir forests in western China to store carbon. They learned that the species’ age affects this potential. US forest taxation policies also have some influence on the capacity of the country’s carbon sinks. A carbon sink value evaluation model based on real option theory demonstrated that the price of carbon sinks has a positive influence while the transaction cost and discount rate have a modest negative impact on the project value.

Enhancing forest management can increase the capacity of forests as a carbon sink and storage source, effectively reducing climate change. The associated forest management practices primarily involve fertilization, crop rotation extension and alteration, tree species selection, and other related activities. Forest leftovers such discarded branches and stumps may be col- lected while lowering the forest’s ability to store carbon to produce forest residual bioenergy. However, by using forest management techniques including fertilizing the forest, lengthening the rotation cycle, switching up how forest wastes are extracted, and leaving high tree stumps, this carbon loss may be made up. Implementing various rotation schedules and manage- ment techniques would help the forest system become carbon neutral. Addi- tionally, [Morais Junior et al. (2019)](#_bookmark41) discovered that different tree species in the forest system had varying capacities for carbon neutralization. Reducing the amount of CO2 in the atmosphere can be accomplished by planting tree species with high carbon storage capacities. In China’s *Pinus tabulae formis* variety of forest, [Ma et al. (2021a, b)](#_bookmark38) investigated the impact of five forest management practices on soil organic carbon stability. They discovered that microbial biomass is the main factor impacting the stability of soil organic carbon, and that natural shrub regeneration regions had the best carbon stability.

Although forest carbon-neutral initiatives can help slow down global warming, they also present many challenges. One of the barriers to entering

the trading market, for instance, may be the implementation cost of taking part in forest carbon neutral initiatives. The implementation of forest carbon neutral projects is also influenced by contract revenue, the quantity of pay- ment supplied, public opinion, and owner preferences.

# The construction industry

The key topics covered in this part are the methods used to produce carbon- neutral structures, the materials used to make them, and the variables influencing their development. The term “carbon neutral construction process” refers to the creation of effective energy consumption plans and the realization of carbon offsetting during the development of new structures. The goal of the European Eco-Life project, according to [Janssens et al. (2017)](#_bookmark23), is to construct several carbon-neutral housing communities in Kortrijk, Bel- gium. Inorder to examine the carbon emissions of a low-carbon home in Kin- men, Taiwan Province, [Liu (2019)](#_bookmark37) separated the building’s life cycle into five stages:

* + - * new building materials;
      * construction;
      * daily energy consumption;
      * maintenance and refurbishment of the building; and
      * demolition of the structure.

According to the findings, daily energy consumption has the biggest carbon footprint, and low-carbon buildings have much lower energy intensity than traditional structures. The neighborhood reduced its members’ overall energy consumption by enhancing energy efficiency, and by using a range of renewable energy generating sources to meet the community’s electrical needs, the neighborhood became carbon neutral.

The integration of photovoltaic (PV) systems and wind turbines on Saudi Arabia’s carbon-neutral residential developments was highlighted by [Krarti](#_bookmark31) [and Aldubyan (2021)](#_bookmark31). They came to the conclusion that the costs and prices of solar and wind energy determine whether carbon neutral buildings would be realized. A unique structural photovoltaic-thermal (PVT) module was presented by [Yao et al. (2022)](#_bookmark68) and used to create a solar-aided PVT heat pump system in the building sector. In comparison to the conventional power delivery system, it greatly decreased carbon emissions, assisting Shanghai in achieving its carbon neutral objective.

Another strategy for achieving carbon neutrality in the construction sec- tor is the zero carbonization of building materials. In addition to lowering

carbon emissions, the use of carbon neutral materials in the building of roads and highways may help promote a sustainable way of life. In their study of the effect of photovoltaic windows (PVCCs) on the life cycle of buildings, [Pierucci et al. (2018)](#_bookmark44) demonstrated this material’s potent capacity for carbon neutrality and energy-saving. Concrete undergoes carbonization, which transforms calcium- or magnesium-rich minerals into stable carbonates for the goal of storing CO2 on a massive scale.

Researchers have also looked at the barriers to the construction of carbon-neutral structures. Using Hong Kong as an example, [Pan and Pan](#_bookmark42) [(2020)](#_bookmark42) discovered through questionnaire surveys and focus group talks that stakeholders typically have a hazy and inconsistent understanding of carbon- neutral buildings, which hinders the construction of carbon-neutral build- ings. According to [Albrecht and Hamels (2021)](#_bookmark4), approximately half of the households in Belgium’s Flemish area cannot afford the refurbishment that would be necessary for carbon-neutral dwellings.

In conclusion, one of the objectives of future study in this topic will be how to estimate carbon emissions in the building sector precisely and analyze thoroughly the carbon neutrality of this business.

# The financial industry

The capital market must be supported in order to achieve carbon neutrality. Due to market investors’ disregard for long-term environmental advantages, China’s growth of low-carbon industries is currently facing a significant financing deficit. Many Chinese cities have adopted pertinent financial pol- icies to support the goal of carbon neutrality in order to address this issue. The central bank proposed in January 2021 to implement the important choices and plans for carbon peak and carbon neutrality, and strengthen the incentive mechanism for green financial policies. The Bank of Beijing released China’s first “carbon neutral” financial bonds on April 21, 2021, for lending to small and micro businesses in environmentally friendly sectors such renewable energy, clean transportation, resource conservation, and recycling. In addition, carbon neutral bonds have also been issued by the provinces of Shanghai, Guangdong, Shandong, and others. The Carbon Peak Fund was established in Wuhan, China in June 2021 to encourage the investment of funds in green sectors. In addition, the Research Group of the Policy Research Bureau of the China Banking and Insurance Regu- latory Commission examined how green finance has developed in China and suggested a course for its future growth. In order to attain high-quality

carbon neutrality, the financial sector should collaborate with the upgrading and transformation of the industrial and energy sectors, rather than being kept outside of the actual economy. The role of commercial banks, green insurance, green finance, and other factors all contribute to carbon neutrality.

# Wastes

The treatment of sewage, outdated electronics, and municipal garbage are the main topics of study in this area. [Hao et al. (2015)](#_bookmark21) analyzed the techno- logical capability of China’s sewage treatment facilities to reach carbon neu- trality in terms of sewage treatment. Water reuse showed the largest potential for carbon neutrality, whereas nutrient recycling had the lowest, according to [Mo and Zhang’s (2012)](#_bookmark40) investigation of the carbon neutrality of a sewage treatment facility in Tampa, FL, USA. Technical process of turn- ing municipal wastewater into carbon-neutral trash. The proper disposal of used electronics will cut back on greenhouse gas emissions. Refrigerant recycling may significantly lower CO2 emissions, according to research by [Park et al. (2019)](#_bookmark43) using the MERC recycling plant in South Korea as the research object. Another crucial method is the ethical disposal of munic- ipal solid waste. In a medium-sized urban residential region in Europe, [Fer-](#_bookmark18) [na´ndez-Bran˜a et al. (2020)](#_bookmark18) assessed the life cycle costs of municipal solid waste management. It was discovered that improving biogas generation, segregating recyclables for collection, and producing waste-derived prod- ucts might help municipal solid waste recycling systems to become more carbon neutral. Gasification is a novel waste treatment that [Lee et al.](#_bookmark32) [(2021)](#_bookmark32) presented and which helps to realize carbon-neutral communities.

# The aviation industry

Kerosene continues to be the primary fuel for airplanes today. Massive CO2 emissions from the quick expansion of air travel and freight have increased the atmospheric concentration of greenhouse gases and acceler- ated global warming. According to ICCT data, the aviation sector contrib- uted 2.4% of the world’s carbon emissions in 2018, a 32% rise over the previous year. The Carbon Offsetting and Reduction Scheme for Interna- tional Aviation (CORSIA) was set out at the International Civil Aviation Organization (ICAO) conference in 2016 in an effort to attain zero carbon in the aviation industry. It was the first global strategy to reduce CO2 emissions from the aviation sector. The advantages of CORSIA for

the environment were assessed by [Scheelhaase and Maertens (2020)](#_bookmark50). [Sharma](#_bookmark52) [et al. (2021)](#_bookmark52) developed an econometric model to investigate and pinpoint the factors that influence the international aviation sector’s realization of car- bon neutrality, and they stressed the significance of CORSIA for a carbon- neutral future.

To combat climate change, several airlines have implemented appropri- ate measures. The effect of bettering airline operations and using sustainable aviation fuels on lowering aviation carbon emissions was investigated by [Chao et al. (2019)](#_bookmark12) using life cycle assessment and Monte Carlo simulation. Greenhouse gas concentrations may be reduced significantly by substituting sustainable fuels for kerosene, and the demand for air travel can be success- fully decreased by raising ticket prices, which also lowers aviation carbon emissions. To acheive carbon neutrality, the aviation industry realize the “CNG2020” policy which aimed to achieve the zero-carbon emission growth goal of the international aviation industry. [Cui and Li (2021)](#_bookmark14) calcu- lated the carbon emissions reduction allocation ratio for 27 airlines using the data envelopment analysis (DEA) approach. Future analyses of the carbon emissions produced by the aviation sector will still require more sophisti- cated and scientific models. More research should be carried out on ways to make aircraft carbon neutral.

# Agriculture and rural areas

It is impossible to disregard the role that agriculture and rural regions play in reaching carbon neutrality. For instance, the Chinese provinces of Guizhou, Sichuan, and Inner Mongolia all introduced pertinent agricultural measures and policies in succession. The utilization of agricultural waste as a resource and green agricultural production technologies have also been the subjects of studies, demonstrations, and promotion. Agriculture makes a significant contribution to the world greenhouse gas emissions, mostly through the methods used to grow crops and the intestinal fermentation of ruminant ani- mals. According to [Torres et al. (2015)](#_bookmark60), enhancing agricultural production techniques can lessen the effects of climate change. The first carbon-neutral coffee in the world was produced in Costa Rica. [Birkenberg and Birner](#_bookmark6) [(2018)](#_bookmark6) carried out a case analysis of this coffee and discovered that it had a significant potential for reducing carbon emissions. A sustainable carbon-neutral viticulture that is utilized to make wine was developed by [Chiriaco et al. (2019)](#_bookmark13) and results in a decreased contribution to climate mit- igation. [Boaitey et al. (2019)](#_bookmark8) used cattle ranchers in Alberta, Canada, as an

example to assess the impact of a strategy to reduce greenhouse gas emissions in the livestock sector. They discovered that adopting new types of feed and raising better cow breeds can reduce carbon emissions, but this decrease would be impacted by geographical heterogeneity. Solid fuels continue to be the main source of energy in rural regions today, with little clean energy being used. Utilizing renewable energy is crucial for creating carbon-neutral communities and reaching carbon neutrality.

# Other areas

In addition to the aforementioned areas, research on carbon neutral has also been carried out in the domains of tourism, transportation, and many others. A low-carbon transition is necessary for tourism in order to reach carbon peak and carbon neutrality. Based on an energy/economy/environment/ engineering (E4) model, [Tattini et al. (2018)](#_bookmark58) concluded that shorter travel times and faster bus speeds will increase decarbonization efficiency. In order to analyze the efficacy of three energy choices (electricity, hydrogen, and hybrid hydrogen-electricity) in Iceland’s transportation sector, [Shafiei](#_bookmark51) [et al. (2017)](#_bookmark51) employed a system dynamics model, where electricity takes into consideration both economic advantages and carbon neutrality. Stronger urban and transportation plans will help to create a city that is more carbon-neutral, sustainable, and healthy. Regarding biomanufacturing, [Tan et al. (2021)](#_bookmark57) noted that employing the concept of raw material diver- sification will support biological carbon neutrality and the sustainable growth of social economy. The idea of carbon neutrality has generally been used in the transformation of all industries to low-carbon production. For- estry, building, banking, and other sectors have all contributed to the achievement of carbon neutrality, enhancing the field of study on the sub- ject. In the future, more pertinent study will be required.

# Concluding remarks

The increasing web of industrialization and international trade through globalization has increased reliance on and overuse of fossil fuels that inflate the presence of greenhouse gases in the environment. The presence of greenhouse gases raises the global temperature steeply, which causes envi- ronmental issues. Therefore, the global community needs to look for alter- natives to fossil fuel use through means of technology and other reforms. The good news is that world leaders have realized the significance of low fossil fuel use and the importance of having a healthy environment which

is free of drastic climate changes. In this regard, the world community has gathered and shared ideas about reducing the levels of carbon emissions. Currently, 4.5% of countries have attained carbon neutrality, and many others have pledged to reach carbon neutrality targets by 2050–70. The pledges focus on decarbonization technologies and initiatives, negative emissions technologies, carbon trading, and carbon tax. Based upon the lit- erature, the few possible remedies are as follows:

1. Renewable sources of energy should be chosen in place of fossil fuel- based energy sources.
2. Dietary habits should be reviewed, in light of the need to control food waste and consumption of meat.
3. Forests and pastures should be restored where possible.
4. Low-carbon agriculture methods should be adopted.
5. Local transportation systems need to be comprehensive, adequate, suf- ficient, and technologically favorable to target carbon low emissions.
6. The production and use of plastic materials should be minimized. The use of renewable energy sources will reduce reliance on fossil fuels. Car- bon dioxide emissions are largely due to the use of these fossil fuels. Chang- ing dietary habits will be quite instrumental in maintaining the environment. The use of plastic materials and waste of resources have become very com- mon in almost every country. The well-directed focus and practice can increase the probability of having the better climate. The fast-paced reduc- tion of forests and pastures has posed an increasing level of threat in terms of climate change. Governments should engage the local community to boost the trend of not leveling forests for commercial purpose, and should legally bind them to plant trees for each tree they cut for commercial use. Carbon dioxide emissions due to transportation are increasing day by day given pop- ulation and related commuting increases. Cities need to have definite, com- prehensive, and technologically fuel-efficient public transport. This will reduce reliance on nonfuel-efficient vehicles and discourage the use of pri- vate cars for commuting.

It is worth appreciating that the global community has taken on climate change as a global issue. This has led to the idea of combating carbon emissions as a global responsibility. World leaders have gathered many times to engage academics for discussion to reach the best possible solutions to this ever- worsening issue. The practices highlighted may seem to be easy, but they are important since they are major contributors of climate issues. The world is tied up with hope upon pledges of countries to reach carbon neutrality that the planet will be released from the issues caused by climate change.

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