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# Carbon footprint of global passenger cars: Scenarios through 2050

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ABSTRACT

Individual ownership of passenger cars has raised significant environmental concern due to carbon dioxide emissions from their usage. In this study, by establishing a bottom-up accounting framework with country-level resolution, a set of scenarios reflecting the possible trajectories of carbon dioxide emissions from global passenger cars through 2050 are presented. The analysis indicates that carbon dioxide emissions from global passenger cars were 2810 megatons in 2013, accounting for about 8.7% of global energy-related carbon dioxide emissions. Under Business-As-Usual scenario, global car sales will more than double by 2050. It is expected that total carbon dioxide emissions will peak in 2020 at 2923 Mt and then decrease to 2297 Mt by 2050. Carbon dioxide emissions from more developed countries will decrease significantly over time. Meanwhile, less developed countries will show great growth. The gap of per capita carbon dioxide emissions between more developed countries and less developed countries will likely shrink rapidly. The Business-As-Usual scenario does not comply with the Representative Concentration Pathway 2.6 scenario, which is used as a benchmark of sustainability. Only when major mitigation measures are implemented to their full potentials can the sustainability goals be met. It is recommended that policy instruments should be further strengthened with a focus on less developed countries.



## 1. Introduction

Passenger cars are normally defined as motor vehicles designed for transporting people rather than goods, typically with seating for one to eight persons. Compared with other transport modes, passenger cars offer higher comfort, flexibility and convenience. It is a mark of affluence that is commonly pursued to improve quality of life. Global car sales have more than doubled over the past thirty years, from about 29 million in 1980 to 65 million in 2014 [45].

Historically, MDC (more developed countries) were the major car markets, with the U.S., EU and Japan accounting for nearly 80% of global car sales. Car ownerships in these countries have reached levels of between 400 and 500 cars per thousand people. Nevertheless, LDC (less developed countries) historically had relatively lower car sales. Car ownership in LDCs has typically come in under 100 cars per thousand people. However, over the past decade, due to rapid economic growth, car sales in LDCs have reached historic highs. Considering the large population base and immense car diffusion potential in LDCs, global car sales will undoubtedly experience further growth in the coming decades [20].

Rapid growth in car sales and ownership have raised a variety of concerns that go beyond $CO_2$ emissions, including traffic congestion, energy security, resource depletion, air pollution from particulate matter, and smog. For example, in recent years, many emerging large cities in LDCs have been experiencing continuous hazy weather. Although it may come from many sources, this event can be fractionally attributed to increasing exhaust emissions from passenger cars [57].

Yet unlike many of these local impacts from greater vehicular use, climate change imposes global impacts and has become a worldwide concern. As IEA (International Energy Agency) estimated, $CO_2$ emissions from road transport were responsible for 16.9% of global $CO_2$ emissions in 2012 [28]. This finding is further supported by the IPCC (Intergovernmental Panel on Climate Change), which has explicitly stated that without aggressive and sustained mitigation policies, transport emissions could increase at a faster rate than emissions from the other energy end-use sectors

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**Abbreviations**

| | |
|---|---|
| 2DS | 2 °C Scenario |
| 4DS | 4 °C Scenario |
| ACEA | European Automobile Manufacturers' Association |
| ANL | Argonne National Laboratory |
| ASEAN | Association of Southeast Asian Nations |
| ASIF | Activity-Structure-energy Intensity-Fuel |
| BAU | Business-As-Usual |
| BEV | Battery Electric Vehicle |
| CARB | California Air Resources Board |
| DV | Diesel Vehicle |
| EIA | Energy Information Agency |
| EV | Electric Vehicle |
| FCV | Fuel Cell Vehicle |
| FSU | Former Soviet Union |
| GFEI | Global Fuel Economy Initiative |
| GHG | Greenhouse Gas |
| GREET | Greenhouse gases, Regulated Emissions, and Energy use in Transportation |
| Gt | Gigaton |
| GV | Gasoline Vehicle |
| HEV | Hybrid Electric Vehicle |
| ICCT | International Council on Clean Transportation |
| ICEV | Internal Combustion Engine Vehicle |
| IEA | International Energy Agency |
| IMF | International Monetary Fund |
| IPCC | Intergovernmental Panel on Climate Change |
| JAMA | Japan Automobile Manufacturers Association |
| LBNL | Lawrence Berkeley National Laboratory |
| LDC | Less Developed Countries |
| MDC | More Developed Countries |
| MoMo | Mobility Model |
| Mt | Megaton |
| NBS | National Bureau of Statistics, PRC |
| NEDC | New European Driving Cycle |
| NGV | Natural Gas Vehicle |
| OECD | Organization for Economic Cooperation and Development |
| OICA | Organisation Internationale des Constructeurs d'Automobiles |
| ORNL | Oak Ridge National Laboratory |
| PHEV | Plug-in Hybrid Electric Vehicle |
| RCP | Representative Concentration Pathway |
| SMP | Sustainable Mobility Project |
| UNDESA | United Nation Department of Economic and Social Affairs |
| WBCSD | World Business Council For Sustainable Development |

[32]. Thus, there is an urgent need for understanding the dynamics of $CO_2$ emissions growth from global passenger cars, and identifying key challenges and opportunities in addressing associated emergent concerns.

Several studies have focused on analyzing global passenger car $CO_2$ emissions. One such study is the SMP (Sustainable Mobility Project) [14], which evolved into the IEA MoMo (Mobility Model) [29]. MoMo uses the "ASIF" (Activity-Structure-energy Intensity-Fuel) framework, which considers a wide range of social-economic inputs and outputs. MoMo simulates energy consumption and GHG (greenhouse gas) emissions from the global transport sector under multiple scenarios, and was used as the supporting model for several reports regarding global transport sector, such as the [23] study and the [54] study. A modified SMP model was used to project $CO_2$ emissions from global light duty vehicles [56]. This study concluded that existing fuel economy regulations through 2025 are broadly consistent with a 450 ppm $CO_2$ atmospheric stabilization. Another study developed scenarios for global car stock and $CO_2$ emissions through 2050 based on an 11-region world partition [38]. This study revealed that $CO_2$ emissions from global passenger cars will range from 5.1 gigaton (Gt) to 8.2 Gt in 2050, depending on the approach employed. Abdallah et al. [2] conducted an international comparison of energy and environmental efficiency in the road transport sector.

Compared with global-level studies, country-level studies regarding $CO_2$ emissions from passenger cars have been more intensively conducted. These studies typically employed a bottom-up approach, with country-specific fleet characteristics such as car sales, vehicle use, and fuel economy as basic inputs. These country-level studies were mostly conducted by domestic researchers, who have better understanding of domestic situations, thus offering higher credibility. Bandivadekar et al. [9] assessed the options for reducing fuel consumption from light-duty vehicles in the U.S., concluding that a 30–50% reduction in fuel consumption is feasible over the period before 2035. Palencia et al. [47] developed a bottom-up dynamic accounting model and estimated the energy use and $CO_2$ emissions reduction potential in passenger car fleet using zero emission vehicles and lightweight materials in Colombia. By employing a similar approach, Palencia et al. [48] evaluated the impacts of powertrain electrification, vehicle size reduction and lightweight materials substitution on energy consumption and $CO_2$ emissions of light-duty vehicle fleet in Japan' context. Ajanovic et al. [3] evaluated the impact of more efficient but larger new passenger cars on energy consumption in EU-15 countries, concluding that striving for efficiency improvements can only have very limited success. Hao et al. [17,18] conducted scenario analysis of energy consumption and GHG emissions from China's passenger vehicles, concluding that GHG emissions from China's passenger vehicles accounted for roughly 5% of national total GHG emissions in 2014. Gambhir et al. [15] analyzed the cost and $CO_2$ emissions impact of substituting current vehicle drivetrain types with alternatives in China's context. Generally, studies regarding MDCs mainly focused on evaluating the impacts from fuel economy regulations implementation and technology improvements. Studies regarding major LDCs like China put more focus on projecting the increases of car sales and ownership.

Existing studies provide a solid basis both in terms of methods and database. However, several improvements to these studies may provide better insights and projections. Firstly, most studies from the global perspective employed a region-based world partition. Model structure and databases were specified on a regional basis. Fleet differences on a country level within the same region have been mostly ignored. This level of analysis can reduce model accuracy, as well as the ability to deliver more nuanced country-specific policy implications. Secondly, there is a need for reconciling top-down targets and bottom-up estimations. Studies on these reconciliations from global and regional perspectives have occurred [49]. A framework to allocate global mitigation targets to country-specific and sector-specific targets has been developed. Yet, with the establishment of the RCP (representative concentration pathways) scenarios [31], further investigation and