WIPO Technology Trends

Future of Transportation

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Foreword

Transportation has long been a major driver of human progress. From the invention of the wheel to the era of steam power, from the birth of aviation to dawn of the space age, transportation technologies have shaped societies, expanded economies and brought cultures closer together. These breakthroughs – fueled by our innate curiosity and determination to explore new horizons – have not only revolutionized how we move but also redefined how we live, trade, connect and think.

Today, we stand on the brink of yet another seismic shift. Propelled by the megatrends of sustainability and digitalization, emerging technologies are reshaping the future of transportation. Electric vehicles, autonomous systems, smart infrastructure and digital logistics are no longer distant dreams – they are becoming part of our daily lives. These advances hold the promise of making transport smarter, greener and more inclusive, and addressing challenges like urban congestion, carbon emissions and fair access to transportation.

This WIPO Technology Trends report delves into innovations across land, sea, air and even space. A remarkable 1.1 million patents related to the future of transportation have been published since 2000, a growth rate far outpacing more traditional transportation technologies like combustion engines and catalytic convertors and well ahead of global patenting growth overall.

This momentum reminds us of an essential truth: that transportation has always been more than just a means of getting from one place to another. It is a testament to human ingenuity and collaboration, with intellectual property playing a pivotal role in safeguarding and fostering groundbreaking ideas on a global scale.

By analyzing the latest IP data, scientific literature and industry developments, this report serves as a bridge between cutting-edge research and practical application. Its aim is to equip policymakers, businesses, researchers and others with key insights to guide investments, shape innovation strategies and inspire collaboration – all with the objective of advancing progress towards the 2030 Sustainable Development Goals.

As nations worldwide strive to achieve net-zero emissions and build new forms of connectivity, the future of transportation will profoundly impact us all. At this pivotal juncture, we hope this report inspires bold thinking, collaborative action, and a shared vision of transport that is not only efficient and innovative but also sustainable and inclusive.

Daren Tang
Director General
World Intellectual Property Organization

About the contributors

This report includes contributions from experts in the transportation sector, futurists, intellectual property, policy and innovation. Their viewpoints and comments complement and add context to the information revealed in patent data, addressing issues such as legal and regulatory questions, standards, data protection, infrastructure challenges, and ethical concerns regarding the future of transportation.

The views expressed by the contributors are solely their own and do not reflect the opinions or positions of their affiliated organizations.

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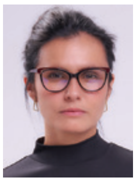

Agnieszka Wiszowaty is a co-founder of Maviator Group, a Polish startup and eVTOL producer, based in Kraków, Poland

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It was prepared under the stewardship of Marco Alemán (Assistant Director General, IP and Innovation Ecosystems Sector) and under the direction of Alejandro Roca Campaña (Senior Director, IP for Innovators Department) and Andrew Czajkowski (Director, Technology and Innovation Support Division), and was led by Christopher Harrison (Patent Analytics Manager, IP Analytics Section, Technology and Innovation Support Division).

The project team led by Christopher Harrison included Lakshmi Supriya (Patent Analytics Officer), Hong Kan (Patent Analytics Officer), Ekrem Çakay (Patent Analyst) and Pooyan Piredeir (Young Expert), all from WIPO's IP Analytics Section, Technology and Innovation Support Division. Former WIPO colleagues Irene Kitsara, Aleksandr Belianov and Craig Dsouza, were also involved in the early stages of the project. Our sincere thanks go to our project partners from EconSight, namely, Kai Gramke, Jochen Spuck, Klaus Jank and Michael Freunek, as well as Frank Passing (IU International University of Applied Science, intuitive.AI), Robert Reading (Clarivate) and Michael E. Adel (Intellectual Landscapes).

The WIPO Technology Trends series is only made possible through the invaluable support of expert contributors, whose insights and knowledge have significantly enriched this report. Such contributions not only ground the analysis in real-world perspectives, but also extend its scope beyond just IP data, illuminating the broader challenges and opportunities shaping, in this edition, the future of transportation. A special thanks therefore goes to Vassilis Agouridas, Arina Anisie, Nikolas Badminton, Manuela Cirilli, Driss El Hadani, Martin Ettlinger, Robert Garbett, Grigore Havârneanu, Yoann Le Petit, Devin Liddell, Michael Maas, Mohamed Mezghani, Seyedeh Fatemeh Moghimi, Thor Myklebust, Eujin Pei, Carlos Ruiz, Juan Carlos Salazar, Jason Schenker, Tom Standage, Thomas Ting and Agnieszka Wiszowaty, as well as to Jaidev Dhavle (IRENA) and Magnus Hakvåg (House of Knowledge) for additional support with the expert contributors.

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Executive summary: Unveiling tomorrow's journeys

This third publication in the series *WIPO Technology Trends* reports on transportation and its future. In a world driven by sustainability and digitalization, understanding the the transformative changes reshaping the transportation sector is more crucial than ever. The report explores how emerging technologies and innovative approaches are revolutionizing the ways in which we move people and goods, while emphasizing the importance of sustainability. Taking for its subject the future of transportation, the report sheds light on the exciting possibilities that lie ahead – from electric and autonomous vehicles to smart infrastructure and digital logistics – and identifies which are the most innovative countries, companies and institutions by investigating the latest transportation patenting trends.

The 2030 Agenda for Sustainable Development

As we move toward 2030, our goal is to identify and analyze the technology trends shaping the future of transportation. By focusing on sustainability and digitalization, the transportation sector can meet not only the demands of a rapidly changing world, but also contribute to the broader goals of economic growth, social inclusion and environmental stewardship set out in the United Nations 2030 Agenda for Sustainable Development.

The focus of the report is on providing tangible insights for everyone – be they an industry professional, a policymaker, researcher or enthusiast – seeking a deeper understanding of the future of transportation. Through real-world examples and forward-looking analysis, we aim to inspire action and collaboration in creating a more sustainable, efficient and connected transportation system for the global community.

The transportation sector faces the dual challenge of achieving sustainability while at the same time embracing digitalization. Addressing this challenge requires a nuanced approach that balances environmental considerations against the opportunities presented by new technologies. The report emphasizes the need for technological solutions that can navigate the complexities of modern transportation systems, delivering benefits that extend beyond efficiency to include safety, accessibility and user experience.

The structure of the report

The report was developed using a data-driven approach, combining traditional patent searches with AI-powered topic extraction. Patents, scientific literature, press releases and CEO statements were analyzed to gather insights into the latest developments and trends within the transportation sector. The report is structured around four principal transportation modalities – Land, Sea, Air, and Space – and two overarching megatrends – Sustainability and Digitalization.

Technology clusters within transportation

The report identifies four primary technology trend clusters within transportation: namely Sustainable Propulsion, Automation and Circularity, Communication and Security, and Human–Machine Interface (HMI). Together, these four clusters represent those critical areas of innovation crucial to the future of transportation, ensuring that digital systems remain robust and resilient, while also addressing environmental challenges.

Sustainable Propulsion is at the forefront of reducing the environmental footprint of transportation. Electric propulsion, hydrogen fuel cells and other alternative energy sources are key to this effort, driving a shift away from fossil fuels. Such technologies are critical to achieving lower emissions and fostering a more sustainable future within transportation.

Automation and Circularity focuses on streamlining production and promoting sustainability. Technologies like industrial robots, smart factories and additive manufacturing are revolutionizing vehicle production, making it more efficient and reducing waste. Circularity emphasizes the sustainable use of resources, with innovations in biopolymers and recycling processes minimizing environmental impact and aligning with broader sustainability goals.

Communication and Security technologies are essential for the safe and efficient operation of a modern transportation system. Innovations such as lidar sensors, 5G networks, connected vehicles (V2X) and smart city infrastructure enable the real-time data exchange so crucial for the development of autonomous driving, smart traffic management and enhanced safety. Such technologies ensure that transportation systems are not only more connected, but also more secure and responsive to dynamic conditions.

HMI technologies are transforming the way users interact with transportation systems. Advances in touch displays, speech and facial recognition, and extended reality are enhancing the user experience, safety and accessibility. Such innovations make transportation systems more intuitive and secure, improving how individuals interact with vehicles and other transport modalities.

Each of these four technology trends represents a vital area of innovation crucial to the future of transportation. Analysis of patent data reveals a rapid pace of development and adoption, providing insights into how the transportation sector is evolving to meet the demands of a sustainable and digitalized world. Among the key findings are the following:

- There were over 1.1 million inventions (patent families) published between 2000 and 2023 relating to the future of transportation.
- With a compound annual growth rate of 11% between 2000 and 2023, technologies relating to the future of transportation far exceed the 4% rate seen in traditional transportation technologies.
- Patenting in Sustainable Propulsion technologies is driving the Sustainability megatrend, and patents in Communication and Security technologies dominate the Digitalization megatrend.
- Land transport patents dominate, with over 3.5 times the number of patents for the Sea, Air and Space transport modalities combined.
- The top five inventor locations, namely China, Japan, the United States of America, the Republic of Korea and Germany, account for over 90% of all inventions, with recent double-digit growth seen in China, Sweden, Italy and India.
- Pockets of specialism will naturally exist around the world in such a broad industry, including Germany in Land transport, Norway in Sea transport, and France in Air and Space transport.

Future of Transportation

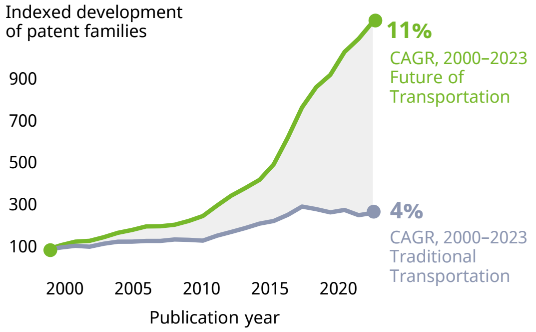
1.1M+

Inventions (Patent families) published, 2000–2023

11% ⬆

The number of patents related to the future of transportation has grown at a compound annual growth rate (CAGR) of nearly **11%**.

In comparison, patents in traditional transportation have grown at a rate of only **4%** over the same period.



Two megatrends and four technology trends

Sustainability

Sustainable Propulsion is driving the Sustainability megatrend.

Digitalization

Communication and Security is driving the Digitalization megatrend.

Sustainable Propulsion
98%
Proportion in Sustainability megatrend

Automation and Circularity
26%
Proportion in Sustainability megatrend

Communication and Security
78%
Proportion in Digitalization megatrend

Human-Machine Interface
15%
Proportion in Digitalization megatrend

Modes of transportation

Most patents related to Land transportation.

Land
82%
Proportion in future of transportation

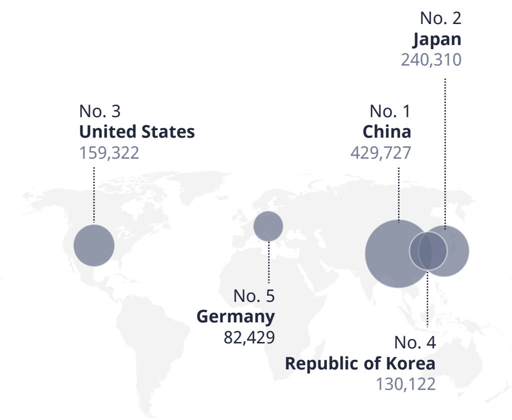
Sea
4%
Proportion in future of transportation

Air
12%
Proportion in future of transportation

Space
7%
Proportion in future of transportation

Leading locations

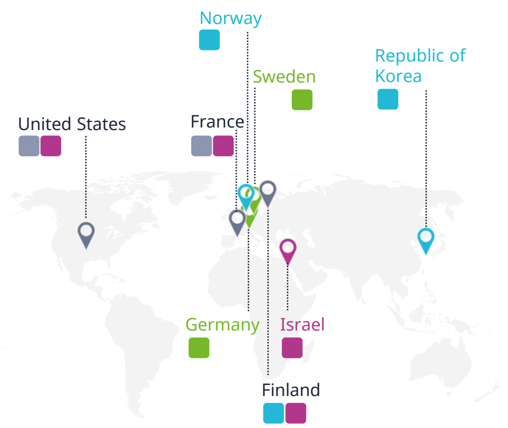
Number of patent families invented in the location



Specialized locations

Notable locations with a high Relative Specialization Index

Land Sea Air Space



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The future of transportation and intellectual property

Intellectual property (IP) plays a crucial role in supporting innovation within the transportation sector. IP rights encourage investment in research and development, fostering the creation of new technologies and solutions. WIPO plays a vital role in this process, by providing support for innovators in making the most of their inventions. Through its various programs and services, WIPO helps inventors navigate the complex world of IP, ensuring that they can protect and commercialize their innovations effectively. By doing so, WIPO hopes to contribute to the growth and development of the transportation sector, helping to drive the transformative changes shaping its future.

Imagining tomorrow, today

This WIPO Technology Trends report on the Future of Transportation offers a forward-looking perspective on what transportation might become by 2030 and beyond. Through envisioning various potential futures, we seek to motivate innovators and inventors in addressing regulatory and standards-related obstacles and developing the groundbreaking technologies needed to bring those visions to life. Our objective is to inspire progress toward a more sustainable, efficient and seamlessly connected transportation network to the benefit of the entire world.

1 Introduction

This chapter outlines our research methodology and the need to use a diverse range of data sources beyond just patents to see the bigger picture and wider context. It then discusses the twin concepts of "market pull" and "technology push" and how innovation thrives on the synergy between the two.

Transportation, encompassing its various modalities including Land, Sea, Air, and even Space, plays an indispensable role in our global economy and society. It not only facilitates the movement of people and goods, it also significantly influences patterns of growth and development across nations and entire regions.

This WIPO Technology Trends report on the Future of Transportation explores the transformative changes that are reshaping the transportation sector. In a world where sustainability and digitalization are driving forces, understanding the future of transportation is more critical than ever. The report explores how emerging technologies and innovative approaches are revolutionizing the way we move people and goods, all the while emphasizing the importance of sustainability. From electric and autonomous vehicles to smart infrastructure and digital logistics, the Future of Transportation report sheds light on the exciting possibilities that lie ahead and identifies the most innovative countries, companies and institutions.

Our focus is on providing tangible insights for those seeking a deeper understanding of the future of transportation, from industry professionals and policymakers to researchers and enthusiasts. Through real-world examples and forward-looking analyses, we aim to inspire action and collaboration in the creation of a more sustainable, efficient and connected transportation system for the global community.

The Global Innovation Index (GII)[1] published by WIPO identifies future innovation waves, with transportation identifed as a key wave in the 2022 edition.[2] The WIPO Technology Trends report on the Future of Transportation builds on this and, while not encompassing every aspect of transportation's future, it focuses in on those key areas where innovation is paramount. As we navigate the evolving landscape of transportation, we unveil the journeys of tomorrow driven by sustainability and digitalization, and explore the technologies paving the way for a more efficient, eco- friendly and interconnected future.

Crafting the future of transportation: our research methodology

The Future of Transportation report is a culmination of extensive research and analysis aimed at providing a comprehensive and insightful overview of the transformative changes occurring within the transportation sector. In crafting this report, we adopted a data-driven approach to data collection and methodology.

1 Global Innovation Index reports available at: https://www.wipo.int/en/web/global-innovation-index.
2 See Figure 20 and Table 11 of Special theme: What is the future of innovation-driven growth – Productivity stagnation or revival? In WIPO (2022), Global Innovation Index 2022. Geneva: WIPO. Available at: www.wipo.int/documents/d/global-innovation-index/docs-en-2022-wipo-pub-2000-2022-section5-en-special-theme-global-innovation-index-2022-15th-edition.pdf.

The structure of the report reflects a commitment to providing a holistic overview. The content of the report is organized into four principal transportation modalities, namely Land, Sea, Air, and Space, recognizing the unique challenges and innovations within each category. Additionally, two overarching megatrends were identified that transcend the four modalities: Sustainability and Digitalization. These two megatrends are central to an understanding of the future of transportation, shaping as they do the industry advancements across the board.

To assure the accuracy and relevance of the information presented, we leveraged a diverse range of data sources (Figure 1.1). Patents played a vital role in the research, allowing us to identify groundbreaking innovations and technologies related to the future of transportation. By conducting thorough patent searches on a global scale, valuable insights were gained into the latest developments and trends in transportation modalities, sustainability and digitalization.

In addition to patents, we conducted a literature review, delving into academic and industry sources. Peer-reviewed journals, research papers and industry reports were instrumental in shaping our understanding of emerging transportation technologies, trends and best practice. This literature review provided a solid foundation for our analysis.

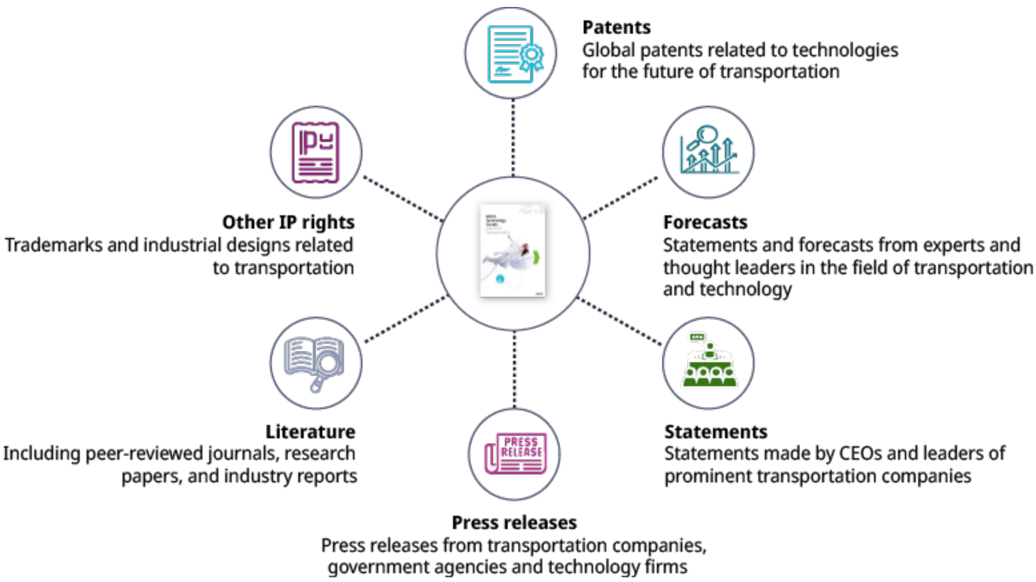
Monitoring press releases from transportation companies, government agencies and technology firms was another aspect of our data collection process. These press releases provided timely and relevant information about recent developments, partnerships and innovations within the transportation sector. They also served as a valuable source of real-world insights.

Furthermore, we examined the statements made by CEOs and leaders of prominent transportation companies. These offered a unique perspective on strategic visions and insights into the future of transportation. Understanding the direction in which industry leaders were steering their organizations was integral to our analysis.

To gain a comprehensive overview of the future landscape, we also considered statements and forecasts from experts and thought leaders in the field of transportation and technology. These forward-looking statements helped us identify emerging megatrends, and challenges and opportunities shaping the future of transportation.

To see the bigger picture and wider context, a diverse range of data sources, beyond just patents, were used in the making of this report

Figure 1.1 Data sources for this report



Source: WIPO.

Market pull and technology push: the driving forces of innovation

Throughout our exploration of the future of transportation, we remained acutely aware that innovation often thrives on a synergy between “market pull” and “‘technology push.” These twin concepts have guided our journey into the four principal transportation modalities – Land, Sea, Air, and Space – shaping our understanding of how innovation unfolds.

What is market pull and technology push?

Market pull innovation arises from consumer demand or market needs, driving development to address specific problems. Technology push innovation originates from scientific or technological advancements, introducing solutions or products that create new opportunities, often ahead of demand. Both approaches influence how ideas are developed and brought to market.

Technology push

One facet of our approach involved delving into the concept of “technology push.” Here, advancements in technology or research drive the development of new products or services, often without immediate consumer demand. This phenomenon underscores the idea that innovation is steered by the possibilities that emerging technologies offer, regardless of whether a clear market demand exists.

In our quest to identify technologies influenced by “technology push,” we turned to specific data sources. Patents – with their wealth of inventive ideas – took center stage in the research. Traditional patent searches were augmented by AI-powered topic extraction, creating a hybrid approach. This innovative blend allowed us to both harness the structured information contained in patents and uncover latent connections and trends within the vast patent landscape.

Patent databases uncover pioneering inventions and innovations, offering a glimpse into the future. Patents, as a repository of innovative thought, often represent the cutting edge of technological advancement.

In parallel, we delved into the world of scientific research. Scientific literature served as a source of the transformative concepts, principles and breakthroughs that might not yet have an immediate practical application, but nonetheless have the potential to reshape transportation fundamentally.

Market pull

Equally integral to our approach was the concept of “market pull.” In this scenario, market demand, consumer needs or regulatory incentives become the driving force behind the development of new products or services. Here, innovation is steered by the tangible demands of consumers, market dynamics or regulatory mandates.

To unearth innovations influenced by “market pull,” we cast our net wide, tapping into a diverse range of data sources. Regulations, with their capacity to shape industries and spur innovation through compliance requirements, became a focal point of the research. Regulatory changes and mandates were analyzed in order to identify those areas where innovation was catalyzed to meet specific standards and requirements.

In addition, we monitored press releases, corporate reports and CEO statements, all rich sources of information on innovations spurred by market demand. These sources provided insights into how companies respond to consumer preferences and needs, adapting their products and services accordingly. Forecasts and market analyses further informed us about the evolving landscape and market trends.

Conceptual note

It is essential to note that while the concepts of "technology push" and "market pull" were instrumental in our gathering technologies, they did not necessarily dictate the structure of the report. Instead, they served as guiding principles in our exploration of the future of transportation, alongside the hybrid approach that combined traditional patent searches with AI-powered topic extraction, offering a multifaceted perspective on technological innovation.

In the chapters that follow, we deep dive into each modality in turn, uncovering the technologies and innovations influenced by these multidimensional forces and including the invaluable insights derived from our analysis of the ever-evolving world of transportation.

2 Overview of transportation and its megatrends

There are a wide range of different modes of transportation across the transport modalities of Land, Sea, Air and Space. In this chapter these are discussed along with two megatrends in particular that are the primary drivers of change within the transportation sector. The critical technologies that align with two megatrends are then broadly categorized into four primary technology trend clusters.

Transportation and its modalities

> Transportation refers to the movement of people and goods from one location to another.
>
> *Cambridge Dictionary, 2024*

Transportation plays an integral role in shaping the global economy and society, by enabling the efficient movement of goods, services and people across regions.[1] This connectivity is essential for linking markets, facilitating trade and promoting economic integration. The seamless operation of supply chains, made possible through effective transportation networks, is vital for meeting consumer demand, managing production schedules and maintaining inventory levels. Consequently, the movement facilitated by transportation stimulates economic growth, enhances productivity and contributes to the globalization of trade, allowing economies to capitalize on their competitive advantages.

The infrastructure that underpins transportation, including roads, railways, airports and seaports, is foundational to achieving these outcomes. Quality transportation networks are instrumental in reducing travel and shipping times, decreasing the costs associated with mobility and improving overall accessibility to markets and resources. The development of such infrastructure can spur regional economic growth by attracting businesses that value logistical efficiency and access to broader markets. This not only serves to transform underdeveloped areas into economic hubs, but also generates employment opportunities and stimulates the growth of related sectors.

Transportation and mobility

Transportation refers to the systems, modes and infrastructures that facilitate the movement of people, goods and services from one location to another. It encompasses various means of transport, including road, rail, air and waterways, and involves the use of vehicles, networks and facilities designed to support these activities. Transportation is a critical component of

1 See, Transport. World Bank Group. Available at: www.worldbank.org/en/topic/transport.

the economy and society, enabling the distribution of products, access to markets and the connectivity of communities.

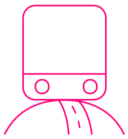
In contrast, mobility is a broader concept that extends beyond the simple act of transportation. It encompasses the ability and freedom of people to move around within a space, reflecting the ease with which individuals can access different locations and opportunities. Mobility includes not only physical movement facilitated by transportation systems, but also those socioeconomic factors that influence an individual's ability to travel, such as having affordable, accessible, and inclusive transport options.

While both transportation and mobility are crucial for the functioning of modern societies, within the context of this report our focus will be primarily on the transportation aspect. We aim to delve into transportation modalities that enable movement. By concentrating on transportation, the report seeks to highlight the importance of developing robust, efficient and sustainable transportation systems as a foundation for fostering economic growth, enhancing global connectivity, and ensuring equitable access to opportunities.

Modes of transportation

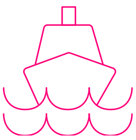
Transportation is a multifaceted sector characterized by various modalities catering to different needs, distances and contexts, making transportation a complex and dynamic component of the global economy and society. In this report, we focus on defining the following four principal transportation modalities, adapted from Rodrigue (see also Figure 2.1).[2]

Land transport



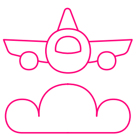
This modality encompasses the movement of people and goods across the Earth's surface. It utilizes vehicles such as cars, bicycles, trains, buses and trucks, which travel along networks of roads, railways and trails. Land transport is integral to everyday life, facilitating commuting, local trade and long-distance haulage. It is characterized by its accessibility and versatility, offering a variety of options to meet different needs and preferences.

Sea transport



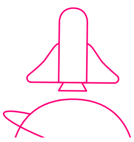
Sea transport involves the shipment of goods and passengers across bodies of water, utilizing vessels such as cargo ships, tankers and ferries on maritime routes plus ports to connect different parts of the world. Sea transport is known for its capacity to move large volumes of goods cost-effectively over long distances, making it a backbone of global trade networks.

Air transport



Air transport is the conveyance of people and cargo through the sky, connecting distant points via airports. This modality utilizes airplanes, helicopters, drones and vertical take-off and landing (VTOL) aircraft for travel and goods shipment. Air transport is distinguished by its speed, making it one of the fastest modes of long- distance travel and an essential service for time-sensitive shipments and global connectivity.

Space transport

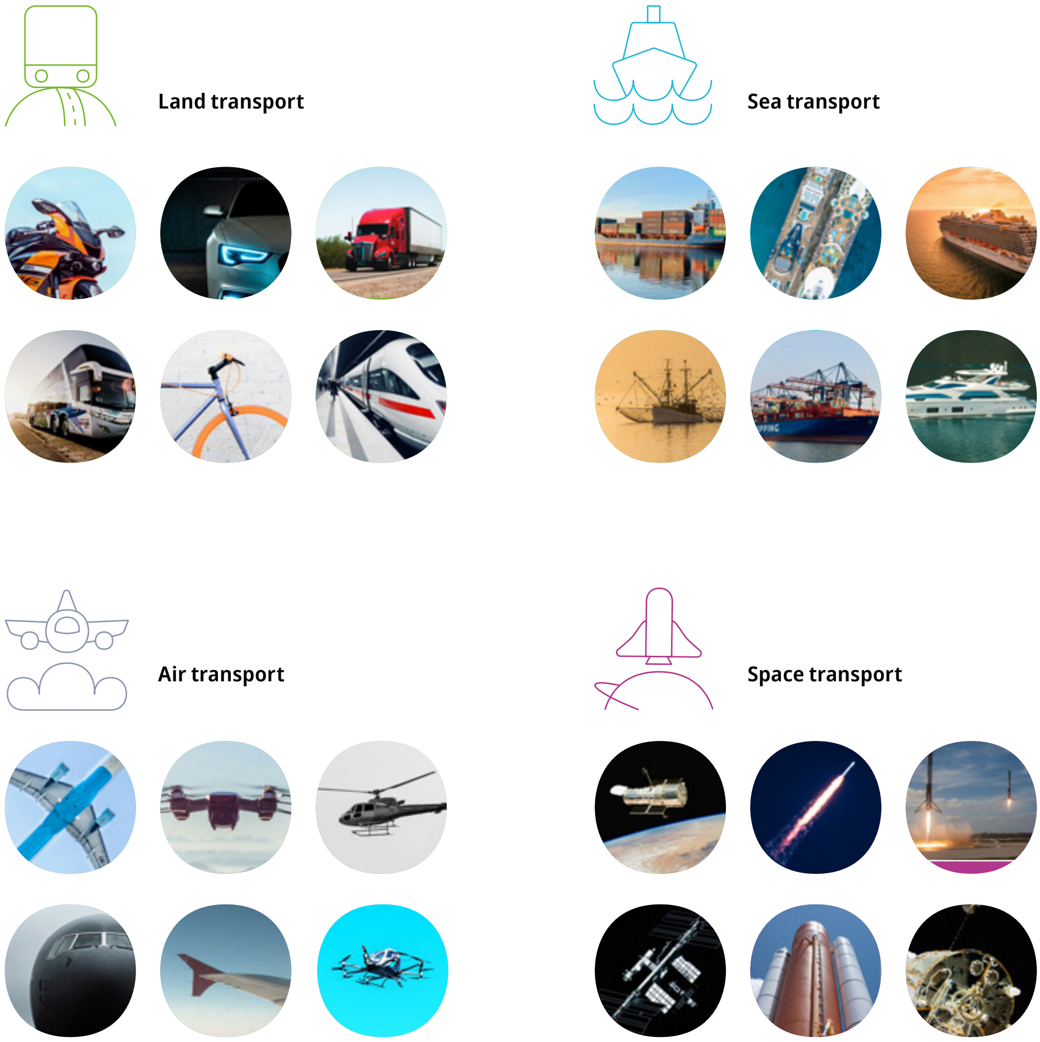


Although not so widely used for commercial purposes as the other modalities, Space transport is rapidly evolving and holds significant potential for the future. It refers to the methods and systems used to send spacecraft and satellites into the higher atmosphere, stratosphere onto outer space. This modality is primarily focused on exploration, communication and satellite deployment, but is also being explored for cargo delivery and human travel beyond Earth's atmosphere.

2 Rodrigue, J. P. (2020). *The geography of transport systems*. Routledge.

The future of transportation is broad and covers everything from cars, trains, buses and airplanes, to ferries, cargo ships, drones and space rockets

Figure 2.1 Transportation across Land, Sea, Air and Space: a visual exploration



Source: WIPO.

The transportation sector, with its various modalities, confronts a host of challenges that extend beyond environmental sustainability to encompass the rapidly evolving landscape of digitalization and technological innovation. While issues like congestion, pollution and greenhouse gas emissions remain significant, the sector also grapples with integrating cutting-edge digital technologies.

To better understand these shifts, we need to explore the megatrends affecting the transportation sector and its modalities in greater detail.

Megatrends within the transportation sector

Imagine a world in 2050 in which autonomous vehicles drive silently through smart cities, drawing power from the road below. Imagine drones delivering packages to your doorstep within minutes of placing an order. And imagine a more distant future where hyperloop trains connect distant cities in a matter of minutes or hypersonic flight allows you to travel from London to Sydney in under two hours. Transportation in this future world is not only faster and more efficient than now, but also cleaner and more sustainable. This vision of the future, while ambitious, is increasingly within reach owing to rapid advancements in technology and a growing awareness of environmental sustainability.

But how can we anticipate a possible 2050 future today? How can one ensure that the transportation systems one is building now will meet the needs of a rapidly evolving world? The answer lies in understanding and leveraging megatrends – powerful, transformative forces that shape the global landscape and drive change across industries, including transportation.

Understanding megatrends

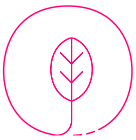
Megatrends are long-term shifts that influence a wide array of sectors and aspects of society. These trends are often global in nature and have the potential to alter the course of economic, environmental, social, technological and political development over decades. The concept of megatrends was popularized by futurist Matthias Horx, who emphasized the importance of identifying such trends in order to anticipate future challenges and opportunities. [3]

In the context of transportation, megatrends are crucial for shaping those strategies and investments that will define the industry's trajectory over the coming decades. By understanding these trends, stakeholders can make informed decisions that align with the future needs of society, ensuring that transportation systems remain relevant and resilient.

Significance of megatrends in transportation

Megatrends play a significant role in shaping the future of transportation by influencing everything from infrastructure development to consumer behavior. Two megatrends in particular – Sustainability and Digitalization – are emerging as key drivers of change within the transportation sector. It is often not only the relevance of the individual megatrends that is discussed, but also their co-existence in the form of a twin transition, particularly in the regional strategies of individual nations. [4] [5] [6]

Sustainability



As the world confronts the realities of climate change and environmental degradation, Sustainability has become a critical focus for the transportation sector. [7] According to the International Energy Agency (IEA), the transportation sector accounts for more than one-third of CO_2 emissions globally. [8] This megatrend drives the development of technologies and practices that reduce the environmental impact of transportation, such as the adoption of, for example, electrified propulsion, the shift to renewable energy sources and the promotion of public and shared transportation options. The Intergovernmental Panel on Climate Change (IPCC) concluded in its report that "transportation can be an agent of sustained urban development that prioritizes goals for equity and emphasizes accessibility, traffic safety, and time-savings [...] while reducing emissions." [9] Moreover, circularity might be beneficial as remanufacturing or reusing components is up to 85% less carbon intensive than making new ones. [10] In alignment with the United Nations Sustainable Development Goals (SDGs) [11] [12] and broader net-zero targets, such strategies contribute to decarbonization efforts and support global ambitions to create sustainable and resilient infrastructure for future generations.

3 Horx, M. (2011). Das Megatrend-Prinzip: Wie die Welt von morgen entsteht. Munich: DVA (Deutsche Verlags-Anstalt).
4 European Union (2023): Digitalisation: Driving the transition towards smart and sustainable mobility. Available at: https://digital-strategy.ec.europa.eu/en/policies/digitalisation-mobility.
5 Brueck, C., S. Losacker and I. Liefner (2024). China's digital and green (twin) transition: insights from national and regional innovation policies. Regional Studies, 1–17. DOI: https://doi.org/10.1080/00343404.2024.2384411.
6 White House (2023): Joint Statement by President Biden and President von der Leyen. The White House. Available at: www.whitehouse.gov/briefing-room/statements-releases/2023/03/10/joint-statement-by-president-biden-and-president-von-der-leyen-2.
7 WIPO (2022). Directing innovation towards a low-carbon future. World Intellectual Property Organization. Available at: www.wipo.int/edocs/pubdocs/en/wipo-pub-econstat-wp-72-en-directing-innovation-towards-a-low-carbon-future.pdf.
8 IEA (2023). Transport. International Energy Agency. Available at: www.iea.org/energy-system/transport.
9 IPCC (2023). Chapter 10: Transport. In IPCC Sixth Assessment Report, Working Group III: Mitigation of Climate Change. Intergovernmental Panel on Climate Change. Available at: www.ipcc.ch/report/ar6/wg3/chapter/chapter-10.
10 Ellen MacArthur Foundation (2023). Climate change and a circular economy for transport. Available at: www.ellenmacarthurfoundation.org/climate-change-and-a-circular-economy-for-transport.
11 See https://sdgs.un.org.
12 WIPO (2024). Sustainable Development Goals and Intellectual Property. World Intellectual Property Organization. Available at: www.wipo.int/web/sdgs.

Digitalization

Digitalization is revolutionizing the transportation sector, ushering in a new era of smarter, more efficient and sustainable mobility. The integration of digital technologies is transforming how transportation systems are designed, operated and experienced, paving the way for innovative solutions and new business models. One of the most significant developments is the rise of autonomous driving, which is projected to generate from USD 300 billion to USD 400 billion in revenue by 2035.[13] This technology not only promises to enhance safety and efficiency, but also to reshape the transportation industry with new services and opportunities.

Moreover, the deployment of smart transport systems is becoming increasingly crucial to improving the efficiency, resilience and sustainability of transport networks. These systems, supported by advancements in digital infrastructure and data analytics, enable more personalized and connected transportation experiences. They also play a vital role in addressing environmental and social challenges, by making mobility greener and more inclusive.

The European Commission has highlighted the potential of digital technologies to revolutionize mobility, making it smarter and more sustainable.[14] Similarly, the United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP) has emphasized the importance of smart transport systems in achieving social and environmental sustainability goals.[15] This megatrend is not only enhancing the functionality of transportation systems, but also creating new business models and opportunities for innovation.

Defining the future of transportation

Traditional transportation has been predominantly linked to the internal combustion engine and fossil fuel-based systems, which have been the backbone of the industry for over a century. However, the future of transportation is being reshaped by the two megatrends – Sustainability and Digitalization. These two trends are driving the development of innovative solutions such as electric and hydrogen-powered vehicles, autonomous systems, smart mobility platforms, and energy-efficient infrastructure.

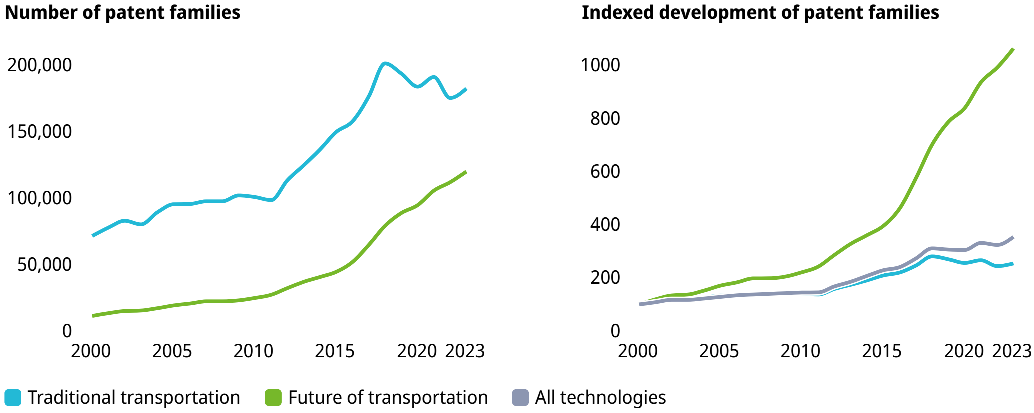
To understand the future direction of transportation, it is essential to analyze the patent landscape associated with these two megatrends. Patents are a valuable indicator of technological innovation, highlighting areas where companies and researchers are investing resources and pushing the boundaries of what is possible.

By examining patent data related to Sustainability and Digitalization in transportation, we can uncover emerging technologies and potential breakthroughs that will define the sector's evolution. This analysis not only reveals where innovation is happening but also provides valuable insights into the competitive dynamics and collaborative opportunities shaping the next generation of transportation.

13 McKinsey (2023). Autonomous driving's future: Convenient and connected. McKinsey & Company. Available at: www.mckinsey.com/industries/automotive-and-assembly/our-insights/autonomous-drivings-future-convenient-and-connected.
14 European Commission (2023). Key technologies for the digitalisation of transport. Available at: https://digital-strategy.ec.europa.eu/en/policies/technologies-digitalisation-transport.
15 UN ESCAP (2023). Regional Road Map to Support Regional Cooperation for the Wider Deployment of Sustainable Smart Transport Systems in Asia and the Pacific, Report. United Nations Economic and Social Commission for Asia and the Pacific. Available at: www.unescap.org/kp/2023/regional-road-map-support-regional-cooperation-wider-deployment-sustainable-smart-transport.

Patenting in the future of transportation has seen substantial growth, whereas growth in traditional transportation follows more general global patenting trends across all technologies

Figure 2.2 Patent publication trends in Traditional transportation and Future of transportation: absolute and indexed growth by earliest publication year, 2000–2023



Note: Future of transportation: innovative and forward-looking systems driven by the megatrends of Sustainability and Digitalization. Indexed development is based on all patent families in the year 2000 being normalized to 100.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

What is a patent family?

A patent family is a collection of patent applications covering the same or similar technical content and all sharing one or more priority documents. Families are used to count inventions and not several patents corresponding to the same subject matter that have been filed in different jurisdictions. In short, one patent family can be considered to relate to one invention.

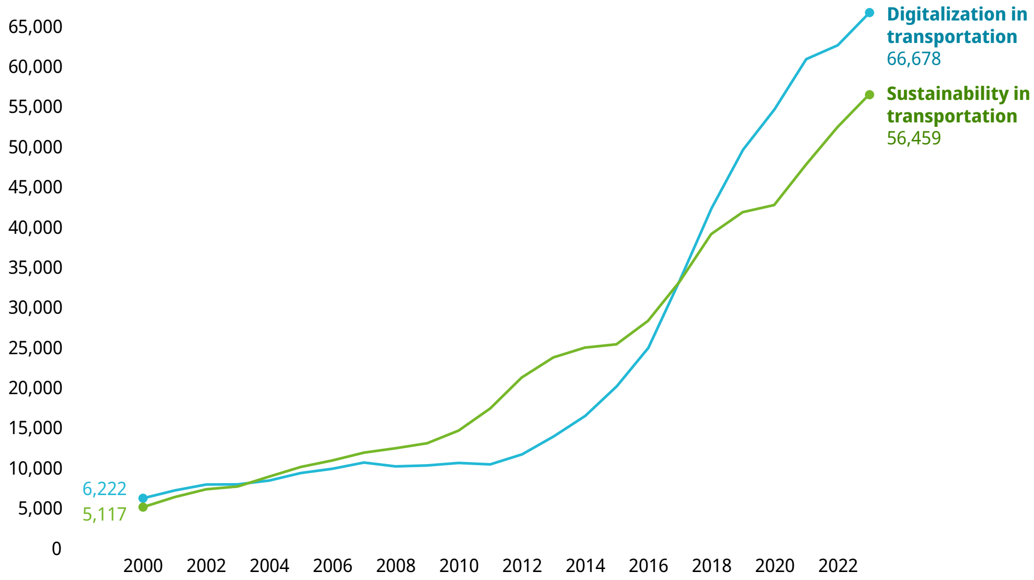
A review of the patent data reveals a clear trend: at a global level, research activities are increasingly shifting toward technologies that will define the future of transportation (Figure 2.2). The number of published patent families in technologies related to the megatrends of Sustainability and Digitalization increased from around 11,000 in 2000 to almost 120,000 in 2023, a compound annual growth rate (CAGR) of almost 11%. In contrast, the number of patent family publications in all traditional transportation technologies has only grown by 4.2% over the same period and the number of traditional transportation patents has even declined in recent years after peaking in 2018. Traditional transportation technologies include all research areas either not or hardly related to the Sustainability and Digitalization megatrends, such as combustion engines, traditional gears or bearings, traditional turbofans, catalytic converters and tires. Due to the high research momentum in future transport technologies, their share in total transport patenting activity has risen from a modest 14% of all patent family publications in 2000 to a share of almost 40% in 2023. This upward trajectory suggests that innovations in areas like Sustainability and Digitalization are becoming increasingly central to the research and development strategies within the transportation sector.

If this trend continues, it could indicate a significant shift in focus away from traditional transportation technologies, such as combustion engines, toward those that promise greater efficiency, connectivity and environmental focus. The consistent rise in the proportion of future-oriented patent family publications hints at a potential transformation in the respective industries whereby sustainable and digital technologies could soon overshadow traditional modalities. Moreover, the growing share of patent family publications in these areas could be an early indicator of the sector's response to the pressures of climate change, urbanization and the digital revolution.

The trajectory of technological innovation within the transportation sector is closely reflected in the dynamics of patent family publications related to Sustainability and Digitalization. As shown in Figure 2.3, these two megatrend areas have seen significant growth over the past two decades, indicating they are playing a critical role in shaping the future of transportation.

Patenting in both the Sustainability and Digitalization megatrends has seen substantial increases over the last decade

Figure 2.3 Patent publication trends of the two megatrends: Sustainability and Digitalization, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Sustainability in transportation

Patent family publications in sustainability-related technologies within the transportation sector have shown consistent growth (Figure 2.3), underscoring the industry's commitment to addressing environmental challenges. In 2000, there were around 5,000 sustainability-related patent family publications, reflecting early efforts to improve fuel efficiency and explore alternative energy sources. Over the next decade, this number grew steadily, reaching around 14,650 by 2010, as innovations in electric vehicles, renewable energy integration and emission reduction technologies gained momentum. The years following 2010 saw continued growth, with patent family publications increasing to more than 28,300 by 2016, driven by advancements and lowering costs in battery technology and the growing adoption of electric and hybrid vehicles.[16] By 2023, sustainability-related patent family publications had grown to nearly 56,500 (19% of all patent family publications in transportation), highlighting the sector's ongoing focus on developing greener and more sustainable transportation solutions.

Digitalization in transportation

Similarly to Sustainability, patent family publications related to Digitalization in transportation have demonstrated a remarkable upward trend from 2000 to 2023. Starting with around 6,000 publications in 2000, there has since been a steady increase, reflecting the growing integration of digital technologies into transportation systems. By 2010, patent family publications had reached around 10,600, signifying advancements in areas such as vehicle automation, data analytics and the initial development of connected vehicle technologies. Growth accelerated further in the subsequent decade, with publications rising sharply to almost 42,300 by 2018. This surge aligns with the rapid adoption of autonomous driving technologies such as lidar

16 See pages 40-41 and 44 of the WIPO Global Innovation Index 2024 - https://www.wipo.int/web-publications/global-innovation-index-2024/en/- discussing the growing electric vehicle (EV) market and detailing the drop in the price of lithium-ion batteries over the last decade, hitting an unprecedented low of USD 139 per kWh in 2023 (down from almost USD 800 per kWh in 2013).

sensors, the expansion of smart mobility solutions and the increasing importance of digital platforms in transportation. By 2023, the number of patent family publications in Digitalization had surpassed 66,600 (22% of all patent family publications in transportation), highlighting the sector's strong focus on leveraging digital innovations to enhance efficiency, safety and connectivity.

The patent data from 2000 to 2023 clearly illustrates the dynamic nature of technological innovation in the transportation sector, with both Sustainability and Digitalization playing increasingly prominent, and equal, roles. In total, there have been 563,257 published patent families in the Sustainability megatrend between 2000 and 2023, and 566,243 published patent families in the Digitalization megatrend. As these trends continue to evolve, they will likely drive the development of new technologies and solutions that will define the future of transportation, making it more efficient, sustainable, and connected.

The dual challenge: Sustainability and Digitalization

The transportation sector faces the dual challenge of achieving Sustainability while at the same time embracing Digitalization. Addressing this challenge requires taking a nuanced approach that balances environmental considerations with the opportunities presented by new technologies. The report emphasizes the need for technological solutions that can navigate the complexities of modern transportation systems, delivering benefits that extend beyond efficiency to include safety, accessibility and user experience.

As we move toward 2030, the goal is to identify and analyze the technology trends that are shaping the future of transportation. By focusing on Sustainability and Digitalization, the transportation sector can meet the demands of a rapidly changing world, as well as contribute to the broader goals of economic growth, social inclusion and environmental stewardship.

We need a cultural shift toward people-centric not transportation-centric cities – Nikolas Badminton, Futurist

Our cities have been built for vehicles and industrial transportation – they have not really been designed for people! People are on the side of those main transportation arteries that go through cities. Consider this in light of the fact that megacities are growing globally, and that eight of the 10 largest megacities are going to be in sub- Saharan Africa. This raises the question of what role transportation is going to play in reshaping our cities. Does it mean that rural areas get further marginalized as people gravitate more toward cities? This is the sort of dilemma we are grappling with.

Infrastructure in most cities today is old. When you add new vehicles we get this weird world of brand new, innovative, cool, fresh, modern technology coexisting with an old infrastructure where there is almost a nostalgic old way of doing things.

Somewhat as a side effect of this, we are seeing new cities being created with whole new ways of thinking about infrastructure and transportation.

Some companies think automated aerial vehicles, or flying cars, is an answer. But putting things in the air doesn't necessarily solve anything for cities. It just creates a raft of new problems, so people aren't going to use these flying vehicles for commuting. Where it becomes interesting is when you go into the connective tissue between cities and to rural areas. I think we are going to end up with hubs with last- mile connectivity driving hubs with autonomous highways from point to point, but also places to go and pick up your goods.

What we are then going to see is a rise of micromobility, like e-bikes and e-scooters, and human-powered mobility. Which may seem like going backward, but the only people that have told us that we need to go forward are the people selling us the vehicles. To say that we are going backward is a technologist’s narrative. To say that we are moving forward in a way that's more egalitarian, more effective, less harmful to the world in terms of emissions, and maybe more human is probably the better way to frame the narrative: changing our concept of what convenience and access in a modern city looks like, will have ripple effects all through.

Today we talk about the “five (or 15) minute city” like it is a revolution or a pipe dream. But that was how cities were in the past, and today we are moving in that direction. There needs to be a cultural shift toward adopting new technologies as we move forward. People need to be taught that there are different options for getting around, from walking to bikes to streetcars to an Uber; not simply jumping into your car the moment you need to get out of the house. There is also a cultural aspect to this – big cars in Northern America, bikes in Copenhagen and Amsterdam, tuk tuks in Bangkok – and that cultural identify is partly defined by the transportation infrastructure we have.

And something important that can be really powerful for innovation and changing the narrative is the storytelling. Be it cartoon, images, videos, sort of like science fiction. Not only can it change perspectives, it can also help sort the good ideas from the preposterous and explore different possible futures.

I think that there’s going to be a huge revolution when people realize that there's a lot that we can lean into, that has already been done and is proven.

Technology trends driving the transformation of transportation

The transportation sector, encompassing Land, Sea, Air and Space transportation, is undergoing a profound transformation driven by key technological advancements.

Through a systematic analysis of scientific research, market trend reports and governmental strategies, several critical technologies were identified that align with the megatrends of Sustainability and Digitalization. These technologies have been broadly categorized into four primary technology trend clusters in transportation, and explained further in Figure 2.4 – Sustainable Propulsion and Automation and Circularity are the two key technology trends for the Sustainability megatrend, and Communication and Security and Human–Machine Interface (HMI) are the two key technology drivers related to the Digitalization of transport. The selection of these four technology trends was driven by their pivotal role in shaping the future landscape of transportation.

A wide range of underlying technologies are driving the development of the four technology trends within the future of transportation

Figure 2.4 Technology trends shaping a digitalized and sustainable transportation sector

Sustainability

Sustainable Propulsion

- Battery technologies and chargers
- Biomass/biofuel/biogas
- Efficient aircraft turbines
- Efficient ship design
- Electric motors
- Fuel cells
- Gearing in electric vehicles
- Green-blue hydrogen/ammonia/ methanol
- H2 electrolysis and fueling stations
- Liquified natural gas (LNG)
- Photovoltaic
- Synthetic fuels

Automation and Circularity

- Additive manufacturing
- Battery and fuel cell recycling
- Biopolymers
- Climate efficient metal processing
- Industrial robots
- Process automation
- Robot control
- Smart factory/pre-maintenance

Digitalization

Communication and Security

- 5G
- Active traffic control
- Cloud technology
- Connected vehicles/infrastructure
- Cyber security
- Digital communication
- GPS navigation
- IoT devices, soft- and middleware
- Lidar, radar, sonar
- Satellites/High-Altitude Platform Systems(HAPS) and High-Altitude Long-Endurance (HALE)
- Smart city
- Vehicle and traffic vision

Human–Machine Interface

- Data gloves, touch displays
- Face recognition
- Head-up displays
- Speech recognition
- Virtual/extended reality, metaverse

Source: WIPO/EconSight.

Sustainable Propulsion is at the forefront of reducing the environmental footprint of transportation. Electric propulsion, hydrogen fuel cells and other alternative energy sources are key to this effort, driving the shift away from fossil fuels. These technologies are critical for achieving lower emissions and fostering a more sustainable future in transportation. In the subsequent analysis, the Sustainable Propulsion technologies are divided into the following sub-groups: batteries, efficient aircraft turbines (only for Air), efficient ship design (only for Sea), electric propulsion, hydrogen/fuel cells, and sustainable fuels.

Automation and Circularity focuses on streamlining production and promoting sustainability. Technologies like industrial robots, smart factories and additive manufacturing are revolutionizing production, making it more efficient and reducing waste. Circularity emphasizes the sustainable use of resources, with innovations in biopolymers and recycling processes that minimize environmental impact aligning with broader sustainability goals. The various Automation and Circularity technologies are divided into three sub-groups: efficient material use, recycling, and smart production.

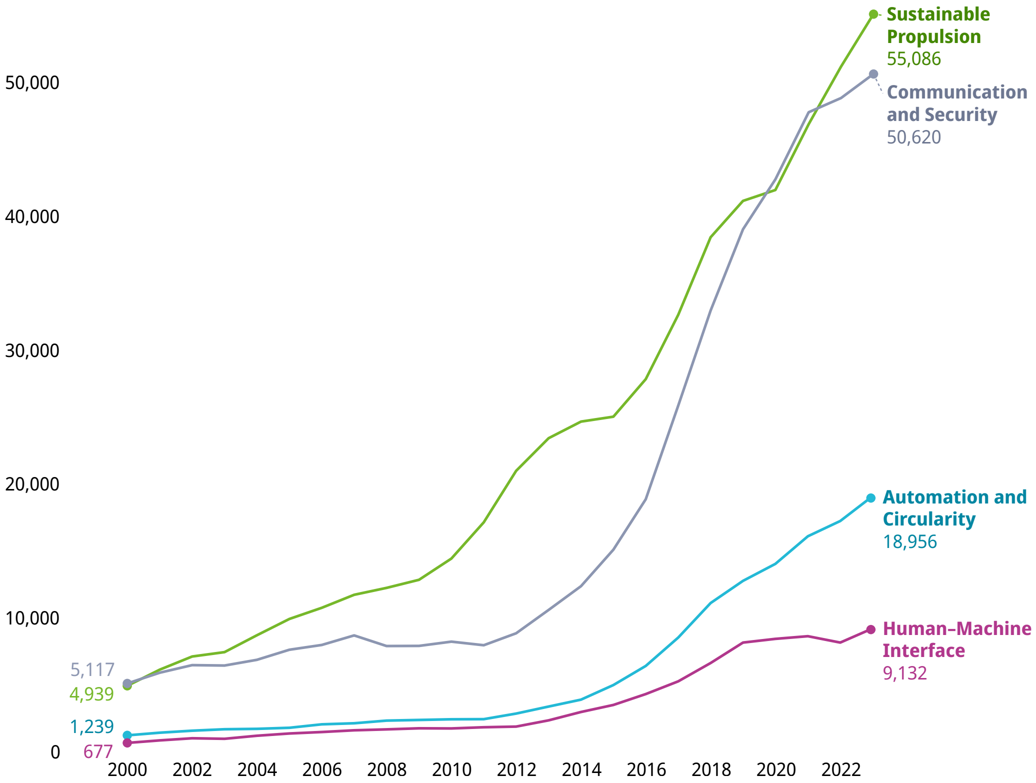
Communication and Security technologies are essential for the safe and efficient operation of modern transportation systems. Innovations such as lidar sensors, 5G networks, connected vehicles (V2X), and smart city infrastructure enable the real- time data exchange so crucial for the development of autonomous driving, smart traffic management and enhanced safety. Such technologies ensure that transportation systems are both more connected and more secure, and responsive to dynamic conditions. For our analysis in the following chapters, we have further divided Communication and Security technologies into four sub-groups: cloud and cybersecurity, device-to-device communication, low-latency communication, and navigation.

HMI technologies are transforming the way users interact with transportation systems. Advances in touch displays, speech and facial recognition and extended reality are enhancing user experience, safety and accessibility. These innovations make transportation systems more intuitive and secure, improving how individuals interact with vehicles and other transport modalities.

Each of these technology trends represents an area of innovation vital to the future of transportation. The analysis of patent data reveals the rapid pace of development and adoption, providing insights into how the transportation sector is evolving to meet the demands of a sustainable and digitalized world (Figure 2.5). In the subsections that follow, the relevance of the four technology trend clusters identified will be explained in greater detail and patent family publications analyzed to give a first glimpse into the trends.

Despite year-on-year growth across the board, patenting in Sustainable Propulsion and Communication and Security technologies are the driving forces shaping the future of transportation

Figure 2.5 Patent publication trends of the four technology trends in the future of transportation, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Collaboration is the key to successful and sustainable innovations in mobility – Yoann Le Petit, EIT Urban Mobility

I believe that the transport sector is currently undergoing three interlinked transformations, driven by significant technological advancements: small, medium and large vehicles are being electrified; they are progressively getting automated; and they can be easily shared and accessed on-demand.

Electrification is at the heart of future-oriented energy and transport policies. Both the NextGenerationEU plan in the European Union and the Inflation Reduction Act in the United States signal growth opportunities for green technologies. Securing a value chain for electric vehicles, from material sourcing to recycling, has become a priority in ensuring a successful transition to low-emission mobility, since innovations in battery technologies, especially lithium-ion batteries, have opened new opportunities to power smaller and larger vehicles alike more cleanly and efficiently.

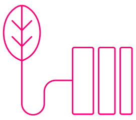
The uptake of battery electric vehicles (EVs) has been particularly dynamic in the passenger car and city bus segments, thanks to innovations in fields such as battery chemistry, vehicle lightweighting and battery management systems, along with a favorable regulatory framework that has EV sales and charging infrastructure as deployment targets. In parallel, the availability of cheaper and more performant batteries has given rise to a variety of so-called "Light Electric Vehicles" (LEVs) such as e-bikes, e-mopeds and e-scooters. These e-bikes and e-scooters are proving popular and provide suitable mobility options, especially for shorter trips in urban areas.

Automation is another major opportunity for the mobility sector. Automated driving features are already omnipresent in new vehicles, improving safety and assisting drivers with lane or parking assistance. Meantime, fully autonomous vehicles are being piloted in a range of locations and circumstances, but full-scale deployment is still to come. However, progress in vehicle automation is already leading to safety improvements and expected to yield further safety benefits. For public transport operators and logistics companies, vehicle automation is expected to alleviate workforce issues and compensate for a lack of bus, tram, metro and truck drivers, which is a widespread global issue, although its severity and root causes vary by region.

Shared mobility has been redefining the way people move around cities. Either in the form of car-sharing, ride-hailing or shared micromobility, it signals a wider shift from vehicle ownership to vehicle use only when needed. The shared mobility sector is fueled by application-based innovations that typically have low barriers to entry, allowing startups to challenge the mobility status quo. For this to happen, efficient data sharing is required, as it enables the deployment of new mobility services and the improvement of existing transport systems.

I strongly believe that the uptake of shared mobility services depends on affordability and user-friendliness. In the mid- to long-term, the balance between a good level of shared mobility options and local, national and EU-level regulations that disincentivize the use of private cars in cities will determine the impact of shared mobility services on vehicle ownership. Effective collaboration between academia, industry and government is essential for successful and sustainable innovations in mobility. Public support is essential for risk-mitigation in early-stage innovations, as is coordination between government, industry and academia to match the new requirements of our mobility systems with the right investment and skills.

Sustainable Propulsion



Sustainable Propulsion is a key trend within the Sustainability domain. It encompasses the development of technologies that reduce the environmental impact of transportation by utilizing cleaner, more efficient propulsion systems. This includes electric propulsion, hydrogen fuel cells and alternative fuels applicable across all transportation modalities.

The shift toward Sustainable Propulsion is driven by the need to decrease greenhouse gas emissions and reduce dependence on fossil fuels. Technologies within this cluster are being developed to power land vehicles, ships, aircraft, and even spacecraft with minimal environmental impact. By focusing on Sustainable Propulsion, transportation systems are moving toward a future where efficiency and environmental stewardship go hand in hand.

Clustering these technologies together highlights the sector-wide push toward Sustainability, in which advancements in propulsion are central to achieving global environmental goals.

The patent data for Sustainable Propulsion shows a strong and consistent increase in patent family publications (Figure 2.5), indicating significant advancements and interest in this area. Starting with about 5,000 patent family publications in 2000, the number has grown steadily, surpassing 10,000 in 2006, and reaching over 55,000 by 2023 (18% of all patent family publications in transportation technologies in 2023).

This significant growth highlights the industry's shift toward sustainable technologies as a response to global environmental challenges. The sharp rise in patents underscores the transportation sector's commitment to developing propulsion systems that align with sustainability goals, making it one of the most dynamic areas of innovation.

Smart electrification strategies are critical in meeting the growing demand for electric vehicles – Arina Anisie, International Renewable Energy Agency (IRENA)

The rapid adoption of electric vehicles (EVs) is set to revolutionize road transport, necessitating an estimated 2.18 billion EVs on the roads by 2050 to align with the Paris Agreement's 1.5 degree scenario.[17] However, this growth poses a challenge for the electricity system, with the 106 terawatt (TWh) hours global electricity demand from EVs, in 2021, projected to reach 4,500 TWh by 2050 – that's approximately 9% of total global electricity demand!

Smart electrification strategies are required in order to provide operational benefits for power systems through flexibility and storage services, and minimise grid investments needed to accommodate increasing load. Smart charging optimizes the charging process using intelligent algorithms that consider electricity prices, renewable generation, local congestion, battery ageing and consumer needs. This allows EV owners to charge when prices are lower, reducing peak demand and cutting the need for additional generation, transmission and distribution capacity.

At the distribution grid level, smart charging can avoid overloading components and assets, improve voltage quality and reduce energy losses. Co-location of EV charging points with solar generation creates synergies, with peak solar generation occurring when most passenger vehicles are parked. Workplace charging, combined with solar photovoltaic rooftop arrays and solar canopies over parking lots, should be encouraged. That said, major investments in charging infrastructure are required to support this transition. IRENA estimates that a cumulative investment of USD 9 trillion for electric charging infrastructure is required between now and 2050. The main barriers to rapidly electrifying transportation are the cost of vehicles and the charging infrastructure they require.

Innovations are emerging designed to overcome the challenges of smart electrification. They include the lack of a clear business model, incompatible payment systems, cybersecurity and data protection issues, and complicated permitting procedures, as well as operating an increasingly decentralised system. Successful solutions require not only technological innovations, but also innovations in market design and regulation, system planning and operation, and business models.

Successful solutions require a systemic innovation approach. However, there is no one-size-fits-all solution – optimal smart electrification strategies depend both on the country context and on system-specific variables. They also must take social and cultural aspects into account. IRENA's Innovation Landscape for Smart Electrification identifies 35 emerging innovations that can support policymakers in building tailored strategies for the smart charging of EVs.

Digital technologies, such as energy management platforms, AI algorithms and blockchain, can improve customer acceptance of EVs and increase renewable energy shares. However, without innovations on the regulatory side – such as dynamic tariffs– and on the planning and operation side – such as increasing grid data transparency – the full potential of digital technologies cannot be unlocked for smart charging.

Automation and Circularity

The Automation and Circularity trend combines two critical aspects of modern transportation: automation, which enhances efficiency and reduces operational costs, and circularity, which focuses on creating sustainable, closed-loop systems that minimize waste. This trend includes advancements in autonomous systems, AI- driven logistics and sustainable manufacturing practices.

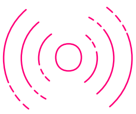
17 UNFCCC. The Paris Agreement: What is the Paris Agreement? United Nations Framework Convention on Climate Change. Available at: https://unfccc.int/process-and-meetings/the-paris-agreement#:~:text=To%20limit%20global%20warming%20to%201.5%C2%B0C%2C%20greenhouse%20gas,and%20decline%2043%25%20by%202030.

Automation technologies are revolutionizing how transportation systems operate, making them more efficient, reliable and scalable. Across all modalities, automation is leading to significant improvements in operational efficiency, from autonomous systems and vessels to automated logistics and supply chain management.

Circularity, on the other hand, focuses on the lifecycle of materials and products within the transportation sector. This includes the development of recyclable materials, sustainable manufacturing processes and the design of transportation systems that prioritize resource efficiency. By clustering automation and circularity together, we underline the complementary nature of these technologies in creating transportation systems that are not just efficient but also sustainable.

Patents for Automation and Circularity technologies demonstrate a significant and accelerating growth trend (Figure 2.5). Starting with just over 1,200 in 2000, patent family publications increased gradually until 2012, when the pace of growth began to accelerate. By 2023, the number of patent family publications had reached almost 19,000 (6% of all patent family publications in transportation technologies in 2023). This surge reflects the growing importance both of automation technologies, such as autonomous transportation and AI in logistics, and circular economy principles within the transportation sector. The increasing number of patents indicates a strong focus on creating transportation systems that are both more efficient and more sustainable, with a clear emphasis on reducing the environmental impact through smarter resource use.

Communication and Security



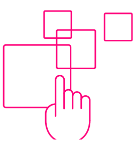
Communication and Security is an essential trend within the broader Digitalization of transportation. It encompasses those technologies that enable secure and reliable communication between vehicles, infrastructure and users across all modalities. This field includes the development of vehicle-to-everything (V2X) communication, cybersecurity measures and data encryption technologies critical for the safe and efficient operation of modern transportation systems.

Across all modalities – whether Land, Sea, Air or Space – communication technologies are enabling seamless data exchange, thereby improving the coordination and efficiency of transport networks. For example, V2X communications allow different elements of the transportation ecosystem to interact in real-time, enhancing traffic management and safety. Security technologies, including encryption, firewalls and intrusion detection systems, are crucial for safeguarding such communications and protecting sensitive data from cyberattack.

By clustering these technologies under the umbrella of Communication and Security, we highlight the essential role of connected and secure systems in the future of transportation, ensuring that digital systems remain robust and resilient.

The trend in patent filings for Communication and Security has also shown significant growth over the past two decades (Figure 2.5). Starting with a little over 5,000 patent family publications in 2000, the number of publications increased steadily, reaching almost 8,000 in 2008, before then accelerating sharply to over 50,000 by 2023 (17% of all patent family publications in transportation in 2023). This upward trajectory reflects the increasing importance of secure and seamless communication in transportation, particularly as autonomous and connected vehicles become more prevalent. The consistent rise in patenting activity suggests that ongoing innovation in this area will continue to be a critical focus as transportation systems become more digital and interconnected.

Human–Machine Interface (HMI)



The Human–Machine Interface (HMI) trend focuses on those technologies that govern the interaction between humans and transportation systems. As transportation technologies become more complex, the need for intuitive, user- friendly interfaces grows. This trend includes innovations in dashboards, touchscreens, voice controls and augmented reality systems that enhance the user experience.

This trend includes a wide range of technologies, from touchscreens and voice- activated controls to augmented reality displays. Such innovations are designed to simplify and enhance the user experience across all transportation modalities. In Land, Sea, Air and Space transport, HMIs are crucial for improving situational awareness, reducing cognitive load, and ensuring that users can operate increasingly complex systems with ease.

By clustering HMI technologies, we emphasize the importance of user-centric design in the future of transportation, where the focus is on creating interfaces that are not solely functional but also enhance safety and accessibility.

Patent activity in the HMI field has also shown a steady increase (Figure 2.5), beginning with over 650 patent family publications in 2000 and reaching over 9,000 by 2023 (3% of all patent family publications in transportation technologies in 2023). This growth reflects the ongoing development of more sophisticated interfaces that improve safety, efficiency and user experience. The rise in patents, particularly after 2013, suggests that, as vehicles and other transportation systems become more autonomous and feature-rich, the demand for advanced HMI solutions will continue to grow, making it a vital area of innovation in the coming years.

Data: the transportation infrastructure's new emission – Tom Standage, The Economist

The big trends I see affecting transportation are decarbonization – not only batteries but also solar power – and the stitching together of transport modalities through digital platforms. This is what I call the "internet of motion." We are going to start to see that it is getting easier and easier to use different modes of transport in a very linked-up way. Several European cities have tried subscription pricing for all modes of transport plus a certain number of hours for other things like car sharing.

I think where we're going to end up is with people subscribing to transport in the same way they subscribe to a mobile phone. If I go to a different country, my transport provider will "roam" onto one of the local transport providers. It will be just like mobile networks. You will have roaming agreements and probably end up with, you know, two or three big providers in every country. The idea will be that multiple modes of transport are treated as a single transport system and your smartphone stitches it all together, because it knows where you are, can handle the payments, and so forth.

However, there is a clear lesson from the past about what we should be watching for from this shift to the internet of motion. Cars were expected to solve the problems caused by horse-driven carriages – piled up manure, rotting dead horses or accidents caused by misbehaving horses. But cars cause other issues – exhaust emissions, congestion, as well as more accidents. Now similar claims are being made for electric and autonomous cars: they will reduce exhaust emissions, lessen traffic and so on. All true. But I think the lesson of history is that we need to look out for the emissions, the exhaust products.

And in the case of the new transport infrastructure, the exhaust product is data. And the question is who has access to that data? Because, in theory, there are some bad things that could happen. The data can potentially reveal quite a lot about people's personal lives, their political preferences and other potentially sensitive things. If you have a digitalized transport infrastructure, that becomes potentially a very powerful tool of coercion and control. And you can imagine how authoritarian or racist societies might implement policies based on that. So we're already starting to see some concern around this.

However, city governments want some transparency and a sharing of this data. This is so they can do transport planning, or so that law enforcement can use it for solving crimes. So there is some tension between how much openness and transparency is imposed on service providers, and the need for personal privacy.

We've been caught out in the past by unexpected exhaust products from transport infrastructure. First it was horse manure, then it was CO_2. This time it's data. We must not make the same mistake again!

3 IP and technology trends shaping the future of transportation

Global patenting activity in the four different technology trends across the four principal transport modalities is analyzed in this chapter, looking at patent growth, technology trajectories, and the top inventor locations and patent owners. Beyond patents, analysis of trademark and industrial design data helps to see the bigger picture and the important role that intellectual property plays in shaping innovation in the transportation sector.

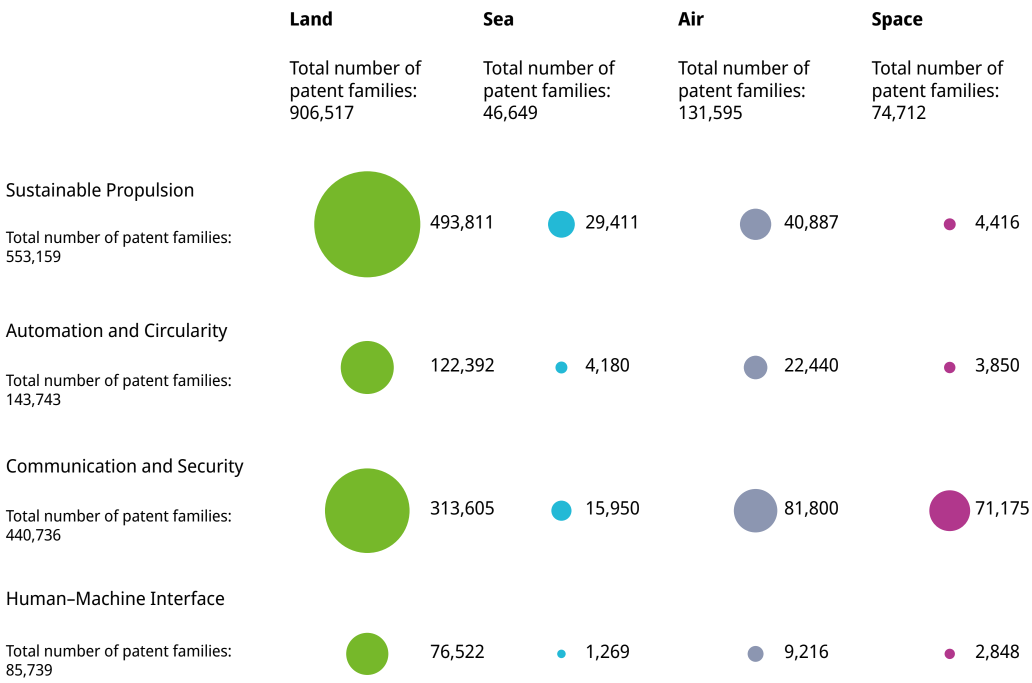
Global patenting activity

This chapter provides an overview of the development of published patent families in the four different technology trends across the four principal transport modalities (See Figures 3.1 and 3.2). The main findings are as follows:

- In terms of research activity, Land transport is by far the largest modality in the field of transportation. This is evidenced by the significant number of patent families in future transport technologies in this area. Since the year 2000, there have been more than 906,000 patent families in the field of Land transport. This figure represents approximately 82% of all identified patents relating to future transport technologies.
- In the domain of Land transport, Sustainable Propulsion represents the most significant research area, with more than 553,000 patent families between 2000 and 2023, followed by Communication and Security technologies, with over 440,000 patent families.
- Air transport constitutes the second largest mode of transport in terms of research activity, with approximately 132,000 patent families published between 2000 and 2023. Communication and Security represents the leading technology trend within Air transportation.
- Patenting activity in Space and Sea transport is considerably lower, with approximately 75,000 and 47,000 patent families, respectively. The primary research areas within Sea transport are Sustainable Propulsion and Communication and Security. In the context of the Space modality, the overwhelming majority of patent families can be attributed to Communication and Security technologies.
- It is notable that research activities in Automation and Circularity technologies are of particular significance within the domains of Air and Land transport. In the domain of Air transport, this technology trend accounts for over 14% of all patent families. In the context of Land transport, the respective share exceeds 12%.
- In comparison to the other technology trends, research activities in HMI technologies remain relatively limited in the Sea and Space modalities. However, HMI technologies are assuming an increasingly significant role in Air and Land transport, with a share of 6% and 8%, respectively, of all patent families in these modalities relating to HMI technologies.

An overview of the distribution of patents within the future of transportation, highlighting the large volumes in Land transport

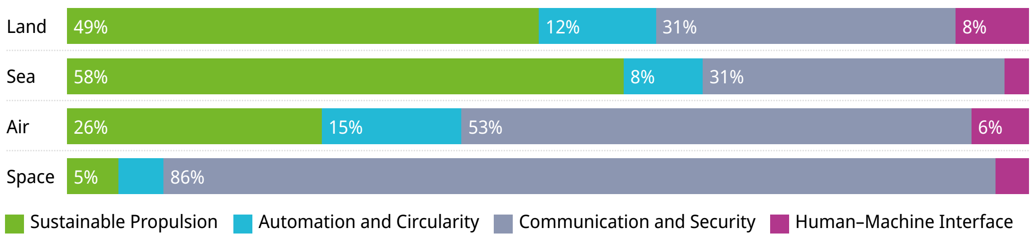
Figure 3.1 Published patent families according to technology trend and transport modality, 2000–2023



Note: Patent family publications can belong to more than one technology trend and/or transport modality.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Sustainable Propulsion is the most patented technology in Land and Sea transport, with Communication and Security leading the way in Air and Space transport

Figure 3.2 Share of the four technology trends in each transport modality, 2000–2023



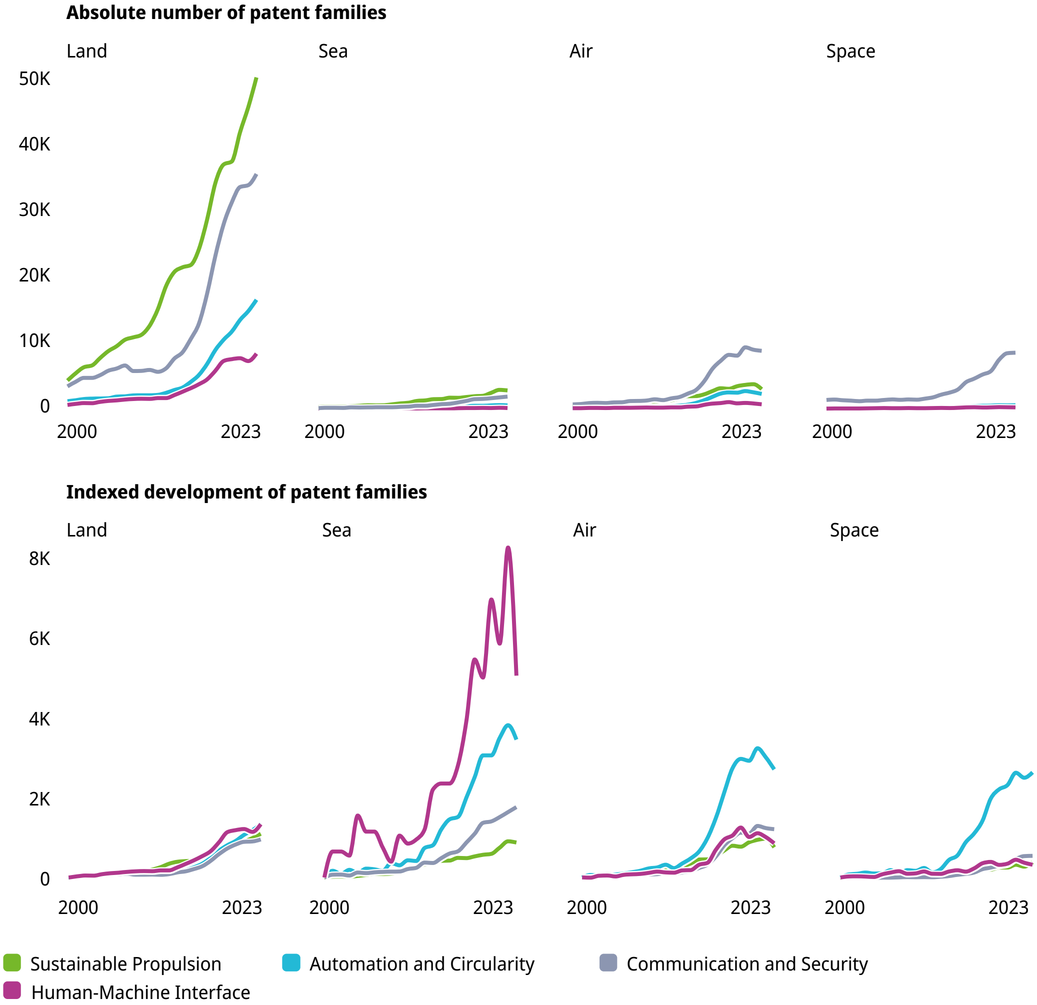
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patent growth and development

Global patenting activity in future transport technologies has increased significantly over the past few years. A closer examination of the development of the key technology trends in each transport modality reveals that this increase in patenting activity was primarily driven by the dynamic development of Sustainable Propulsion and Communication and Security technologies in the Land transport modality (Figure 3.3). Other significant research areas in terms of the absolute number of patent families include Automation and Circularity, as well as HMI technologies, in Land transport, and Communication and Security technologies in both Air and Space transport.

Land transport may dominate in absolute numbers of patents but, in relative terms since 2000, Sea transport and Automation and Circularity technologies show the largest growth

Figure 3.3 Patent publication trends in the four technology trends in each transport modality: absolute number of published patent families and indexed growth, 2000–2023



Note: Indexed development is based on all patent families in the year 2000 being normalized to 100.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

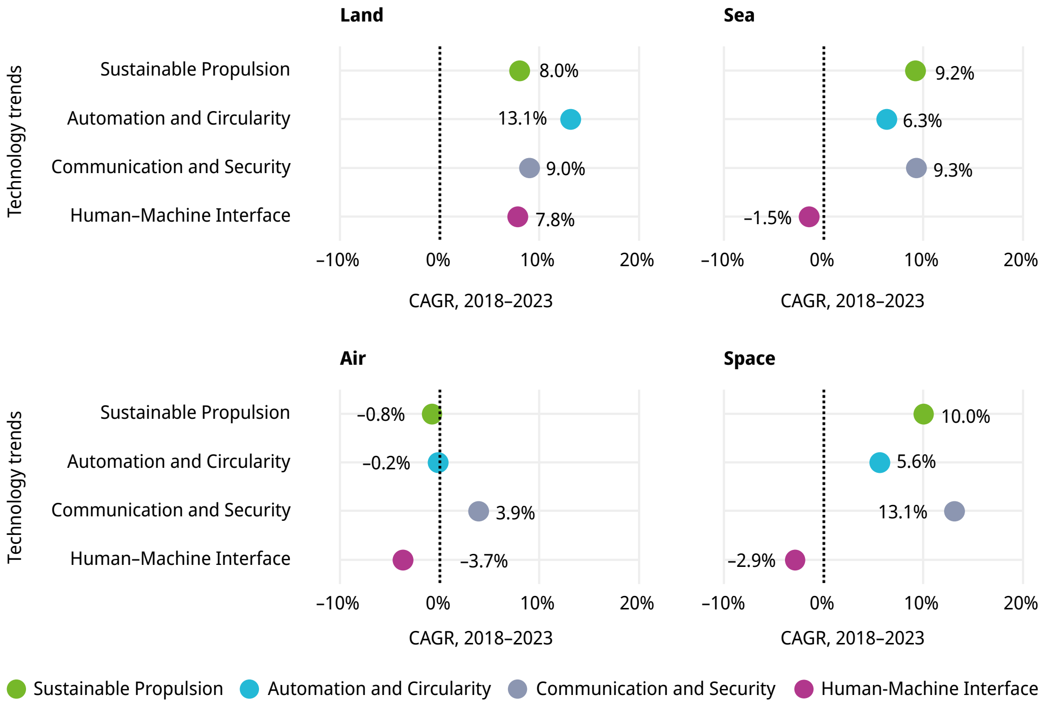
Patent publications for Land, Sea and Space transport have undergone a growth trend, but those for Air transport reached a preliminary peak in 2021 and have since declined. The challenges faced by the aviation industry in recent years, in particular those due to the effects of the COVID-19 pandemic, are likely to have contributed to the recent slowdown in patenting activity.

An analysis of patent growth rates in recent years (2018–2023) shows that patent families have increased in most technology trends and in each modality since 2018 (Figure 3.4). Communication and Security technologies in Space transportation and Automation and Circularity technologies in Land transportation have experienced the highest growth rate, each recording an compound annual growth rate of published patent families of 13.1% since 2018.

In contrast, patenting activity in HMI technologies has decreased in most transport modalities in recent years, with Land transport being the only exception. In addition, patent growth in Air transport technologies was also only moderate, as only Communication and Security technologies in Air transport showed positive growth rates during the same period.

Recent growth has been strong in all modalities except Air, and also across all four technology trends except HMI

Figure 3.4 Growth of published patent families in the four technology trends and in each transport modality, 2018–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

However, focusing on growth rates only serves to ignore the differing levels of patenting activity between different future transport technologies. To address this, the new WIPO Patent Momentum Indicator (see Appendix A.2 for more detail) calculates a score for each of the 16 transport modality-technology trend groupings that reflects both the level of patenting activity and growth dynamics in recent years, in order to identify those technologies having the greatest impact on innovation right now (Figure 3.5). The WIPO Patent Momentum Indicator shows Sustainable Propulsion and Automation and Circularity in Land transport, and Communication and Security technologies in both Land and Space transport as having the highest patent momentum.

Four transport modality-technology trend groupings show a high patent momentum

Figure 3.5 WIPO Patent Momentum Indicator for future of transportation patent families, 2018–2023

Technology trends	Land	Sea	Air	Space
Sustainable Propulsion	High	Medium	Low	Medium
Automation and Circularity	High	Low	Low	Low
Communication and Security	High	Medium	Low	High
Human–Machine Interface	Medium	Low	Low	Low

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

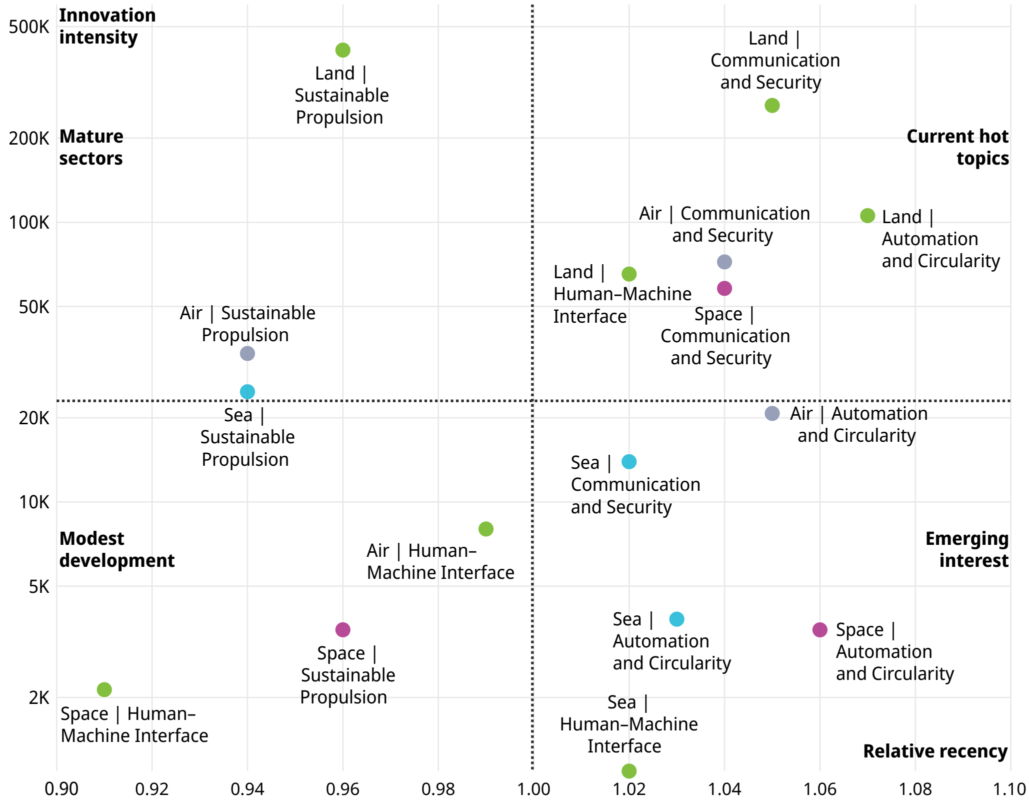
The relative technological maturity of each technology trend in each transport modality, as seen from a patent perspective, can also be assessed using an Innovation Maturity Matrix. This categorizes all future of transportation patent families according to their respective transport modality-technology trend grouping alongside their respective recency, that is, a measure of how recently the future of transportation patent applications in question were filed. [1]

Figure 3.6 shows the Innovation Maturity Matrix for future of transportation patents filed since 2010. It offers a slightly different perspective on the 16 transport modality- technology trend groupings than that shown with the WIPO Patent Momentum Indicator in Figure 3.5. Five of these groupings (including Communication and Security technologies for Land, Air and Space transport) have been identified as current hot topics, meaning they all have a large number of patents and have recorded strong growth in recent years. There are also five transport modality- technology trend groupings (including Automation and Circularity technologies for Sea, Air and Space transport) where the number of patent families is smaller but an emerging interest can be seen in the recent growth in patenting activity related to these technology areas. Whereas this is difficult to detect in Figure 3.3 and Figure 3.4, it is more clearly visible in the Innovation Maturity Matrix. In contrast, the relative recency of Sustainable Propulsion technologies in all four transport modalities is low, suggesting a recent slow-down in the development of new inventions for Sustainable Propulsion technologies, with the maturing of such technologies for Land, Sea and Air transport.

1 See Appendix A.2 for details on the Innovation Maturity Matrix methodology used.

Emerging interest is seen in five transport modality-technology trend groupings, which are smaller in size but show recent patenting activity

Figure 3.6 Innovation Maturity Matrix for future of transportation patent families, 2010–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Visualizing technology trajectories

Patent analysis in broad technology sectors, such as transportation, can be challenging due to several complexities inherent in patent data and the technologies themselves. Broad sectors often encompass diverse and overlapping technology areas and sub-areas, making it difficult to define clear boundaries for analysis. Rapidly evolving technologies, such as urban air taxis and micromobility add another layer of complexity, as emerging fields lack historical data and established classification schemes. In some technology sectors, patents may precede market trends by years, creating a temporal disconnect between technological activity and commercial outcome. Yet while this presents an interpretation challenge it is also a strategic opportunity.

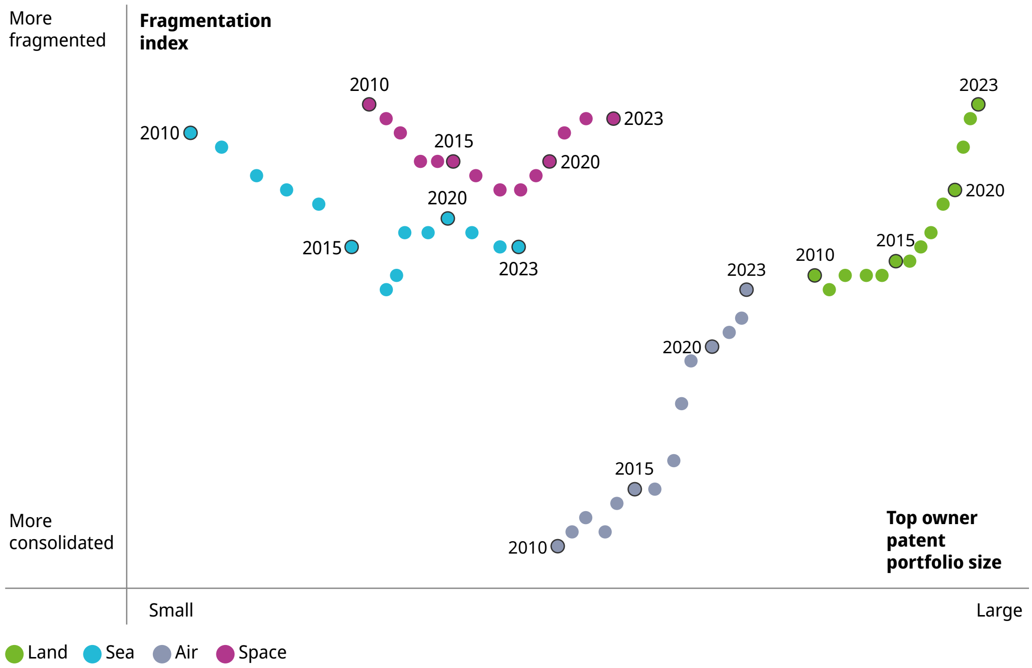
These broad technology sectors can be termed "metalandscapes" because their analysis requires undertaking the patent landscaping of multiple patent landscapes. Analyzing technology metalandscapes using advanced patent analytics to assess trajectories and fragmentation is a new area of research. Adel and Harrison propose the use of Discrete Pareto Analysis (DPA) to analyze patent landscapes, in order to gain graphical insights into technology proliferation and consolidation dynamics across various domains.[2] The study introduces power law analysis to quantify patent family distributions among patent owners, highlighting patterns in patent landscape evolution. This approach relies on the notion that industries display unique 'signature' trajectories which can be useful for predicting market trends, since patenting activity can act as an early indicator that distinguishes between market growth due to leader dominance and that due to new player entry.

2 Adel, M. and Harrison, C., Unravelling technology meta-landscapes: A patent analytics approach to assess trajectories and fragmentation, World Patent Information, Volume 76, 2024, 102256, ISSN 0172-2190, https://doi.org/10.1016/j.wpi.2023.102256.

Using this approach, the metalandscapes for Land, Sea, Air and Space, are displayed in Figure 3.7, which shows the industry trajectories for each modality in the future of transportation since 2010. The fragmentation index depicts the degree of fragmentation (i.e. influx of new players), as opposed to consolidation (i.e. dominance by top patent owners). Fragmentation may be interpreted as an indicator of innovation since the entry of new players encourages competition and inventive diversity. In such environments, smaller companies and new entrants must differentiate themselves, often leading to novel ideas and unique approaches to problem-solving. A lack of market dominance by a few large firms ensures that innovation is not stifled by entrenched interests seeking to protect their existing technologies or market position. Furthermore, fragmented industries provide greater opportunity for collaboration and the cross-pollination of ideas, as diverse players experiment and share insights, creating a dynamic ecosystem that drives technological progress and economic growth.

Land and Air transport are rapidly fragmenting industries, showing increasing innovation with the entry of new players encouraging competition and inventive diversity

Figure 3.7 Technology trajectories of the four transport modalities, 2010–2023



Source: WIPO in collaboration with Michael Adel, based on patent data from EconSight/IFI Claims and LexisNexis PatentSight, November 2024.

The trajectories for the four transport modalities shown in Figure 3.7 are interpreted as indicators of market dynamics, providing a better understanding of innovation and the competitive landscape within the transportation sector. The data shows that Air transport is the most consolidated (least fragmented) modality, dominated by a smaller number of larger players, such as Airbus, Boeing, Safran and RTX (formerly Raytheon). The trajectory for Air transport shows increasing fragmentation over the past decade which appears to be, in part, due to the growth of the drone industry in recent years.

As we have already seen, Land transport is the largest of the four modalities studied, and its trajectory shows a rapid fragmentation since 2017, most likely due to the growth and emergence of the EV market. Space transport is the most fragmented modality over the time period studied, possibly driven by the lower costs of building, launching and operating space technologies compared to the preceding decades, enabling more startups and smaller companies to participate.

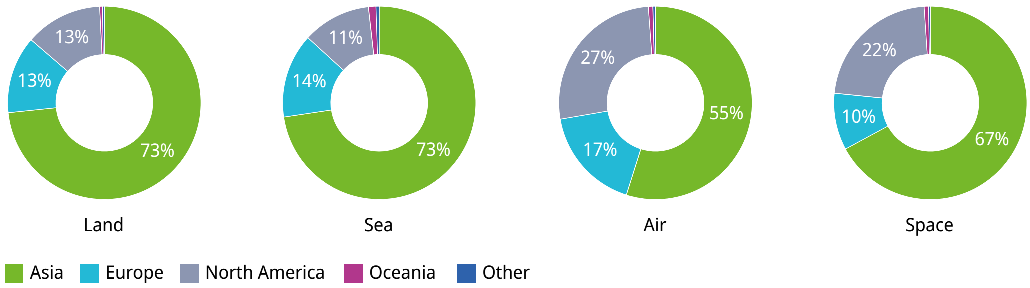
Sea transport, on the other hand, show the trajectory of a more traditional industry with gradual growth over time and decreasing fragmentation in the metalandscape, but with a small uptick in recent years. This suggests an increasing dominance by the main industry players, with less new entrants entering the market, but that we may have reached an inflexion point. It will be interesting to see if, in the future, the recent upward trajectory continues in a similar to manner to that seen in Land and Air transport. This could be due to a possible lagging response within the maritime sector to innovations related to the future of transport, namely the Sustainability and Digitalization megatrends and the four related technology trends discussed in this report.

Top inventor locations

At the regional level, there is a strong dominance of patenting from Asia across all four principal transport modalities, especially in Land and Sea transport (Figure 3.8). North America has relative strengths in Air and Space transport, but there is very little patenting activity relating to future transport technologies in Africa, Latin America or Oceania.

Asia dominates across the board, but North America shows relative strengths in Air and Space transport

Figure 3.8 Regional breakdown of patents in each of the four transport modalities, 2000–2023

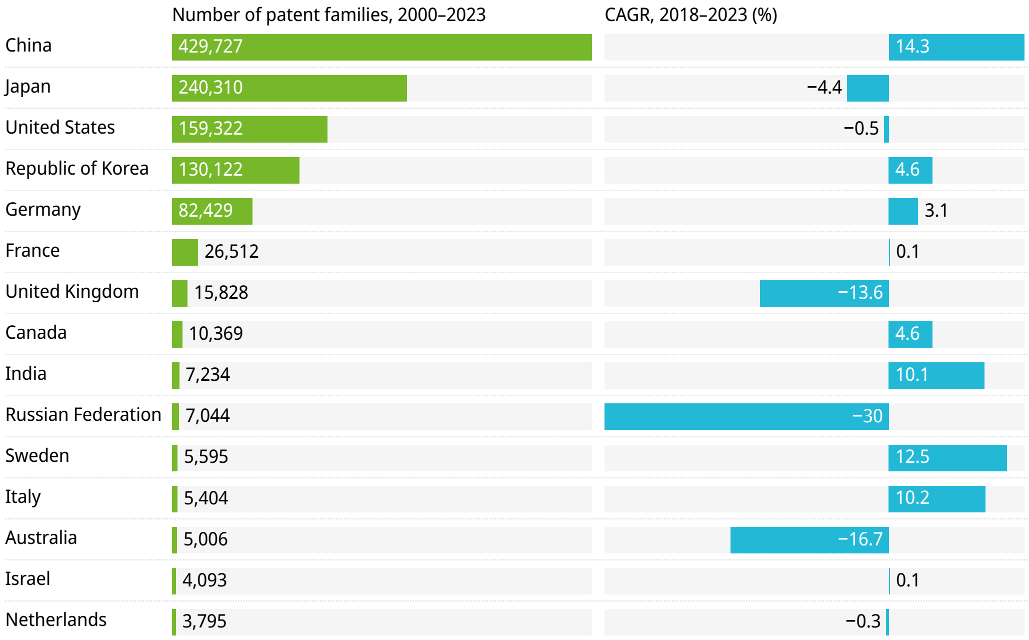


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

At the country level, five locations – China, Japan, the United States, the Republic of Korea and Germany – have accounted for the majority of patenting activity in future transport technologies (Figure 3.9). Collectively, these five locations generated almost 1,050,000 patent families in future transport technologies between 2000 and 2023, representing over 90% of all patent families in these technologies.

The top five locations account for over 90% of all inventions, with recent double-digit growth seen in China, Sweden, Italy and India

Figure 3.9 Patent family publications and annual growth in the top inventor locations



Note: If a patent publication lists inventor addresses from more than one location, the patent publication is assigned to all listed locations.

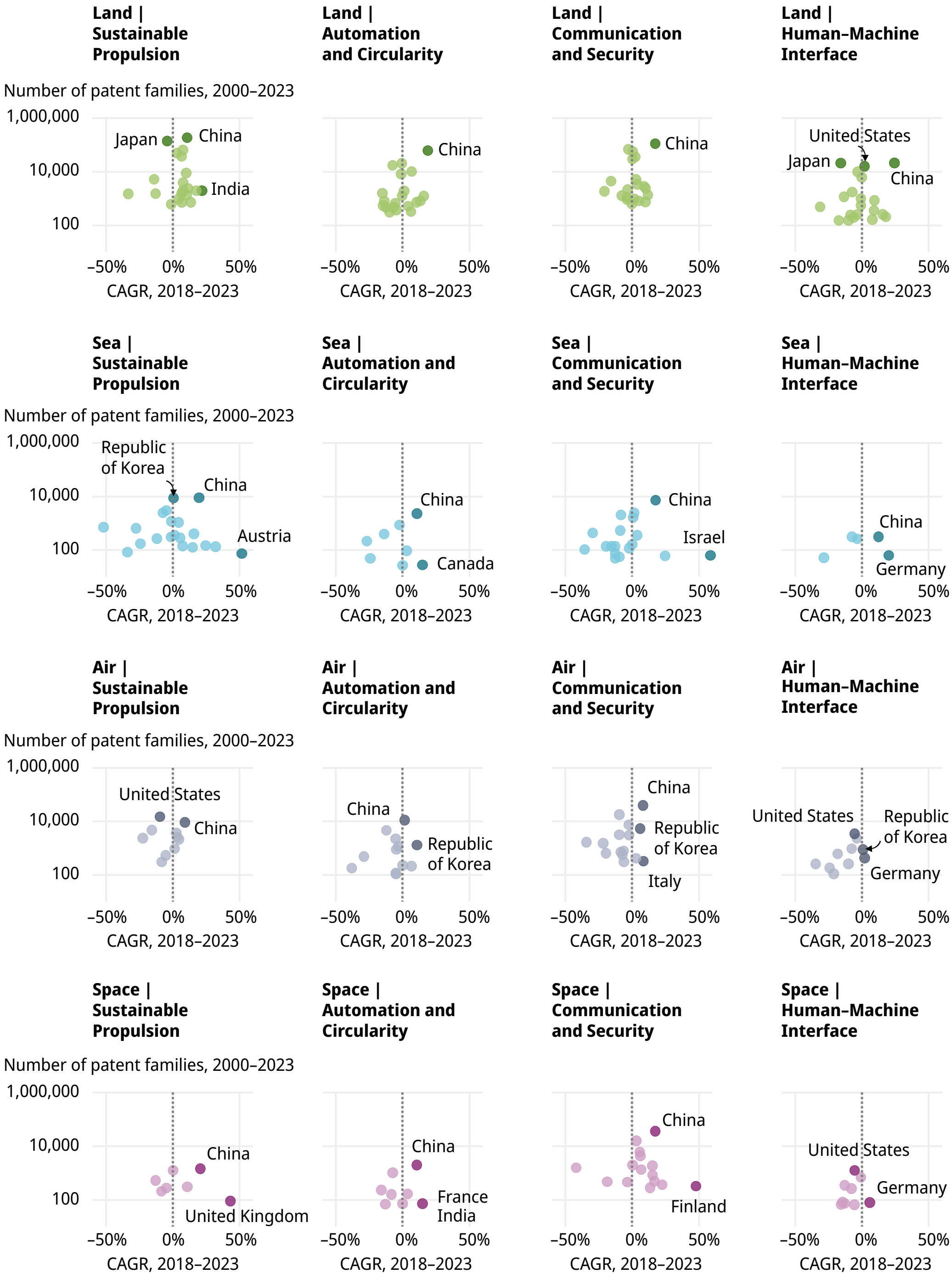
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

However, when we examine the overall increase in patenting activity in recent years, a different picture emerges. Since 2018, China has been the primary driver of global patenting activity in future transport technologies, with a growth rate of 14.3%. The number of annual patent families from China almost doubled, from 38,900 in 2018 to almost 76,000 in 2023. Among the other top 15 inventor locations, only India, Italy and Sweden have also achieved a double-digit patent growth rate, but they still lag behind China.

The growth in other major research locations, including the Republic of Korea and Germany, has been significantly lower than that observed in China. It is also worth noting that there has been a negative growth rate in patent families from Japan and the United States between 2018 and 2023, as well as in Australia, the Netherlands, the Russian Federation and the United Kingdom.

Looking at the size and growth of the top inventor locations in each transport modality-technology trends grouping reveals many underlying stories to be explored further

Figure 3.10 Performance of the top inventor locations in the four transport modalities across the four technology trends



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Closer analysis reveals large volumes of patenting from China across all four transport modalities and, despite the large absolute numbers, China has demonstrated recent growth across all four transport modalities (Figure 3.10). The United States has a significant global market share in the development of future Air and Space transport. However, the largest total number of patents from the United States between 2018 and 2023 has been in Land transport. Japan's research activities are heavily focused on Land transport technologies.

Germany has strengths in Land transport and has increased its patent families in this area in recent years, although their patent growth was highest in Space transport technologies.

The Republic of Korea is one of the global leaders in the development of future Sea transport technologies, although Land transport is their most significant field in terms of absolute patent numbers.

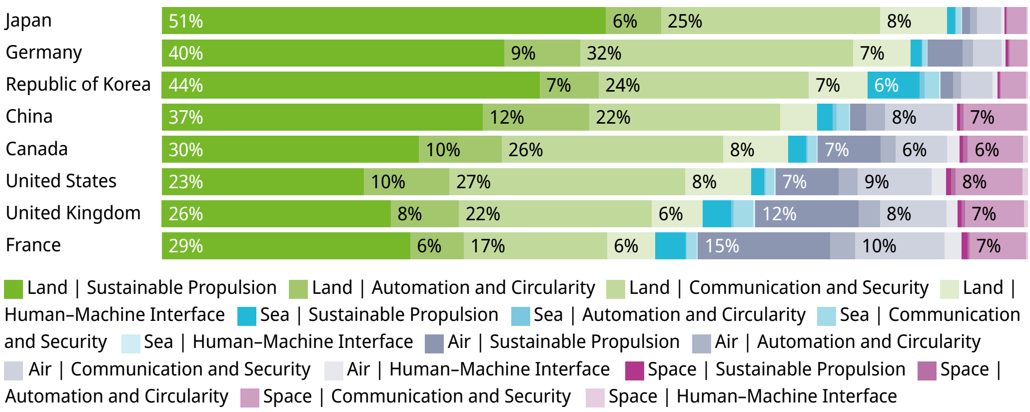
Looking in Figure 3.10 at patenting activity in the four technology trends instead of according to transport modalities, China again leads in all four technology trends in terms of number of patent families and patent growth. The United States has technological strengths in HMI and Communication and Security technologies. Japan has a large number of patent families in HMI and Sustainable Propulsion technologies, but patent family growth was negative in both of these technology trends between 2018 and 2023.

Germany has strong growth in Sustainable Propulsion technologies since 2018, but limited recent growth in the other three technology trends. The Republic of Korea has achieved dynamic growth rates in Sustainable Propulsion and Automation and Circularity technologies, but has seen a negative growth rate in HMI technologies in recent years.

An alternative view of the proportional research priorities of the top inventor locations, based on the number of published patent families in each of the 16 transport modality-technology trend groupings, is shown in Figure 3.11.

Land transport is the primary focus of research, accounting for over 80% of all future transport patents in Japan, Germany and the Republic of Korea

Figure 3.11 Research priorities of top inventor locations, ordered by descending share of Land transport patents, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The Relative Specialization Index (RSI)[3] compares patenting activity in two or more locations within the same technology area. RSI is a measure of a location's share of patent families in a particular field of technology as a fraction of that location's share of patent families in all fields of technology. It accounts for the fact that some locations file more patent applications than others in all fields of technology.

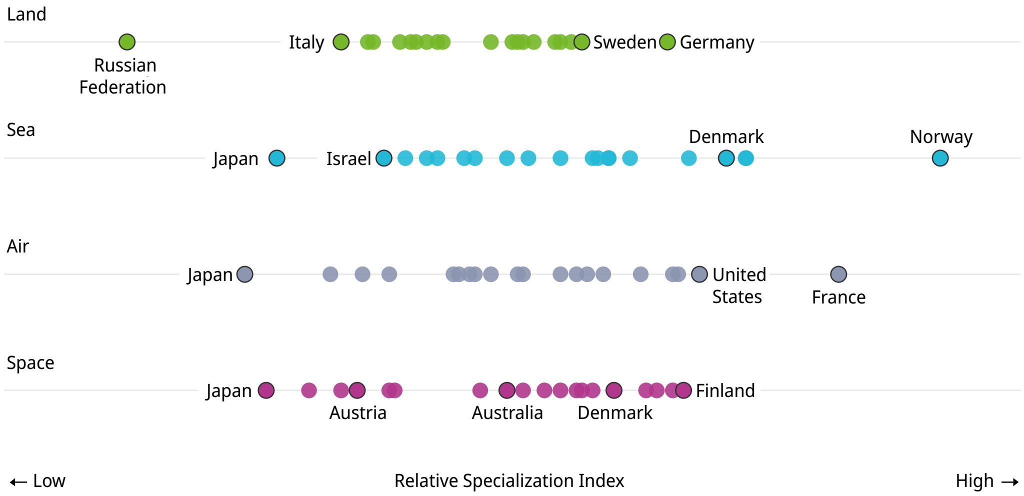
In other words, RSI has the advantage of providing a comparison of two locations' patenting activity in a technology relative to those locations' overall patenting activity. The effect of this is to highlight locations that have a greater specialism in the technology area studied than would be expected from their overall level of patenting, and which might otherwise appear further down in the top inventor location lists, often unnoticed.

Figure 3.12 provides a detailed view of the Relative Specialization Index in future transport patents across various inventor locations, each demonstrating unique strengths and focuses.

3 See Appendix A.2 for more details on how the Relative Specialization Index is calculated.

Highlighting pockets of specialism across the world, such as Norway in Sea transport, France in Air transport and Germany in Land transport

Figure 3.12 Relative Specialization Index (RSI) across top inventor locations in the four transport modalities, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

For Land transportation, Germany and Sweden demonstrate the highest levels of specialization, reflecting a strong emphasis on innovation in this domain. These findings align with their advanced automotive and rail industries, which are globally renowned.

In Sea transportation, Norway and Finland emerge as the most specialized inventor locations. This focus is likely rooted in a maritime heritage and reliance on shipping and related industries. Norway's high specialization underscores its significant role in maritime technology, while Finland's innovative efforts in this area are similarly notable.

Air transportation is led by France and the United States, which exhibit the highest RSI values in this modality. This is indicative of a robust aerospace industry and longstanding leadership in aviation innovation. These two countries are also very strong in Space transport, although Finland also stands out here, but its absolute number of patents is small compared to those of France and the United States.

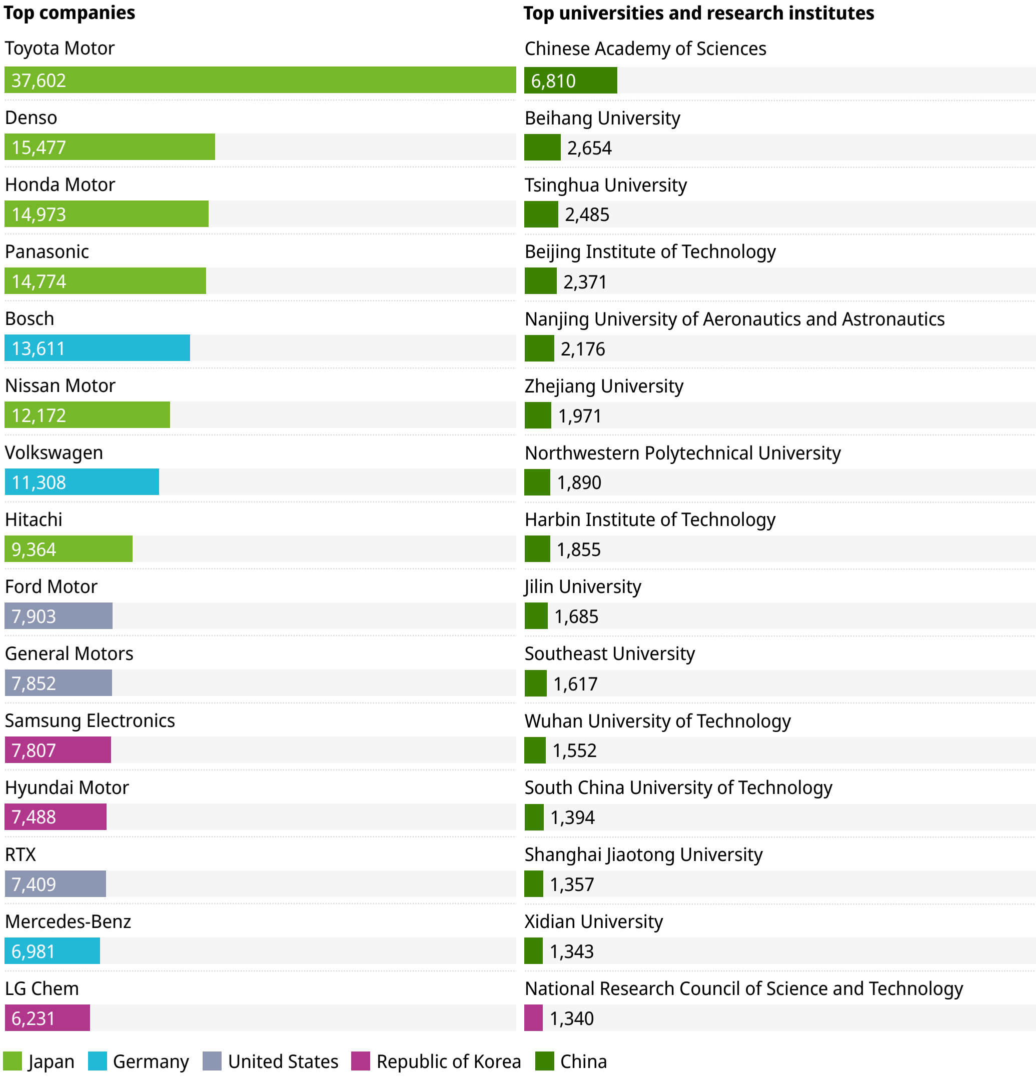
Overall, the findings reveal clear national priorities and capabilities. Inventor locations such as France, Germany, Norway, Sweden and the United States lead in their respective areas of transportation innovation, supported by strong industrial ecosystems. Meanwhile, Finland's leadership in both Sea and Space transportation highlights its ability to excel in specialized niches. In contrast, Japan's broader but less focused approach to transportation technologies may indicate a strategy of diversification rather than deep specialization in any one modality.

Top patent owners

At the company level, Japanese, German and US automobile manufacturers and suppliers are the top patent holders over the entire period analyzed, from 2000 to 2023 (Figure 3.13). Toyota Motor published by far the most patents in future transport technologies, with almost 55,000 patent families. US aerospace and defense conglomerate RTX Corp is the only company in the top 15 whose main research focus is on a non-automotive transport modality, namely Air transport.

Japan has the largest patenting companies, which feature many of the big automotive manufacturers, but China dominates in patents from academia

Figure 3.13 Top patent owners based on the number of patent families, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

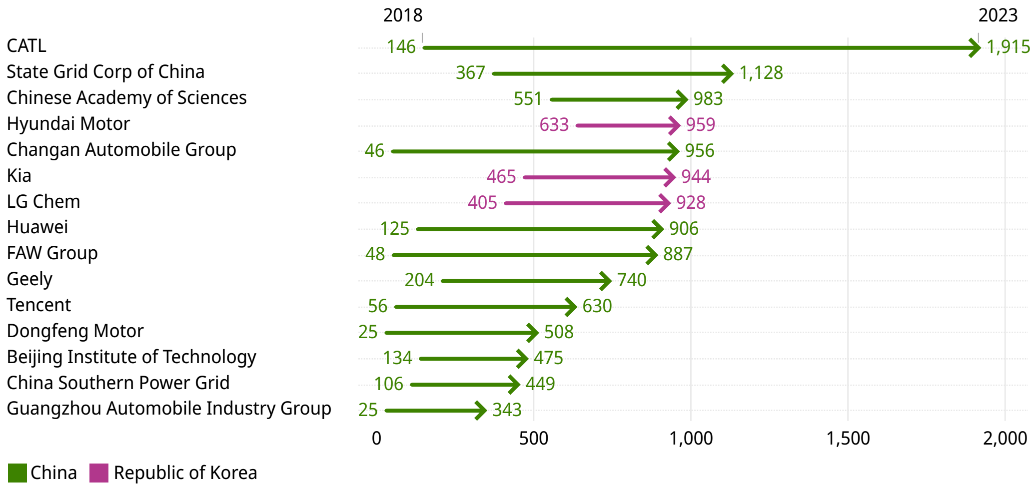
A different picture emerges when looking at the top universities and other research institutes in future transport technologies. China is home to the top 14 research institutes. With more than 6,800 patent families published since 2000, the Chinese Academy of Sciences is clearly in the lead.

Focusing on the increase in annual patent families over the period 2018 to 2023, Chinese companies take the lead, with CATL in first place (Figure 3.14). Again, the list is dominated by automotive manufacturers and suppliers. But there are also companies from other industries in the mix, such as Chinese Utility State Grid Corp of China, Chinese telecommunications company Huawei and Chinese technology company Tencent Holdings.

The top companies shown in Figure 3.13 have a long-standing and well-established position within the transportation industry so, although there are no Chinese companies among the top companies shown in Figure 3.13, the recent increase in filings by Chinese companies shown in Figure 3.14 shows a recent growth in patent portfolio size. It inherently takes time to establish a well-rooted patent portfolio and, with the recent growth shown in Figure 3.14, only time will tell whether any of these companies rises up the rankings and into the list of top companies in Figure 3.13.

China may not have any of the top patenting companies, but the largest growing patent portfolios in recent years are from Chinese patent owners

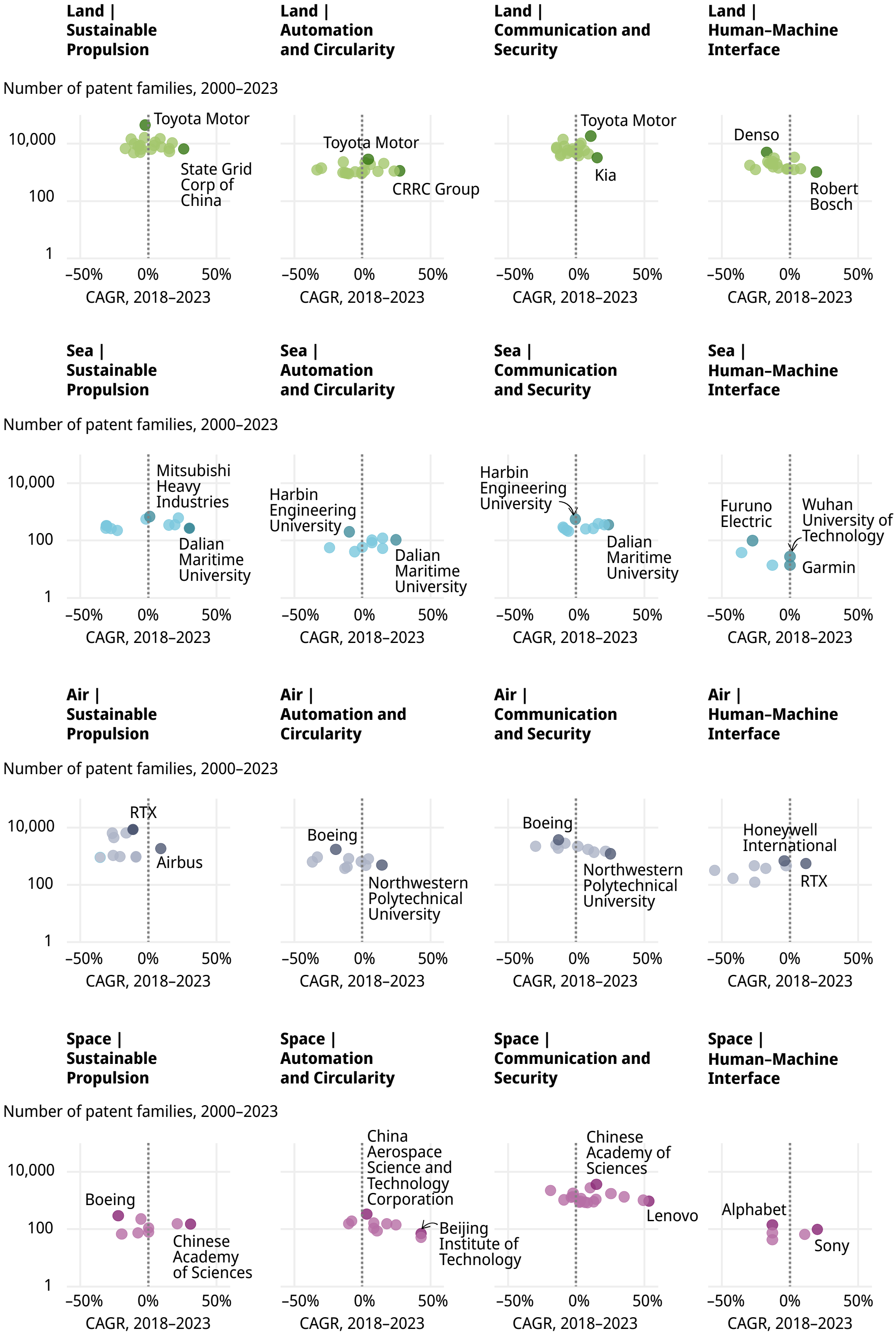
Figure 3.14 Patent owners with the largest increase of patent family publications, 2018–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Looking at the size and growth of the patent portfolios of the top patent owners in each transport modality-technology trends grouping reveals a diverse range of different players, and specialists within certain groupings

Figure 3.15 Top patent owners in the four transport modalities across four technology trends



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Figure 3.15 looks at the top research players in the four transport modalities across the four technology trends from the perspective of both patent portfolio size and compound annual growth rate (CAGR).

Toyota Motor, Bosch, Denso, Honda Motor are the top research actors in future Land transport technologies. Toyota stands out in the Sustainable Propulsion technology trend, in which the Japanese carmaker claims a very high share of almost 9% of all patent families worldwide since 2010. However, the patent growth of the top Japanese companies has been rather slow and even negative in some areas, whereas German companies, such as Bosch, have managed to increase their patent portfolios at a dynamic pace.

China's Harbin Engineering University is the top patent owner in the field of future Sea transport technologies and has grown its patent portfolio very dynamically since 2010. The university has a particularly high global share in Automation and Circularity technologies. Other top research players in future Sea transport technologies are Mitsubishi Heavy Industries, Gaztransport et Technigaz, Wuhan University of Technology and Dalian Maritime University. These four research players have a focus on Sustainable Propulsion and Communication and Security technologies.

The field of future Air transport research is dominated by the United States and European companies. RTX Corp tops the list with a clear focus on Sustainable Propulsion technologies (13% global share). RTX Corp has also shown very high growth rates in all four technology trends in the past. The rest of the top research companies include the aircraft duopoly Airbus and Boeing and the aerospace engine makers Safran and General Electric (GE). However, the patent growth for these companies has been moderate since 2010.

The Chinese Academy of Sciences, the China Aerospace Science and Technology Corporation and the China Electronics Technology Group have published the most patent families in future Space technologies since 2010. The patent growth of these Chinese research players was also exceptionally high. Two other major research players are Boeing in the United States and Mitsubishi Electric in Japan. However, patent families by these two companies declined between 2010 and 2023.

Foreign-oriented patenting activity

Due to the vast size of the overall transportation sector, the following section of this report focus on foreign-oriented patent families – also referred to as international patent families (IPFs) or extended patent families – as opposed to domestic-only ones.

What is an international patent family?

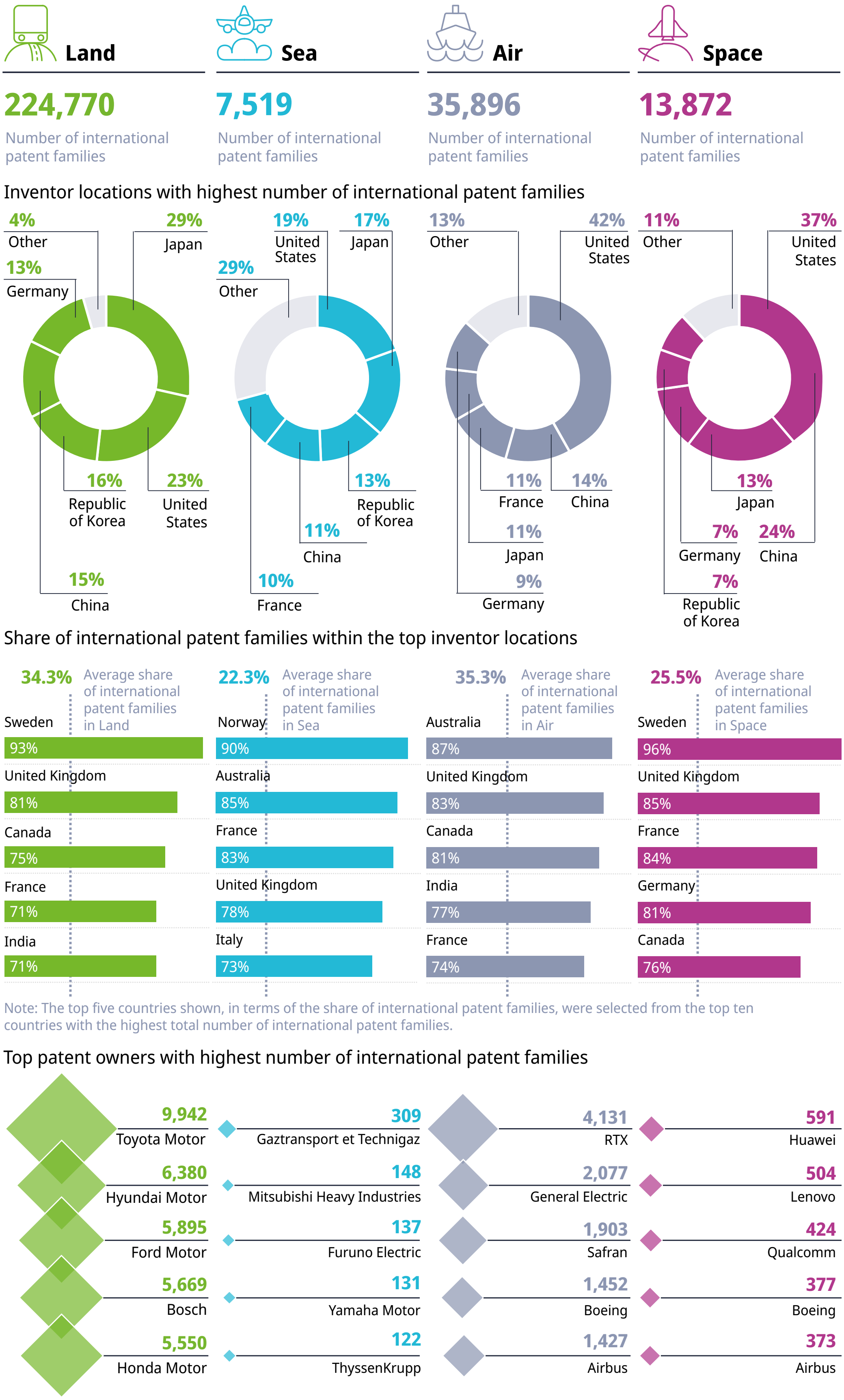
International patent families (IPFs) are a reliable and neutral proxy for inventive activity because they represent those inventions that applicants consider important enough to seek international protection for them. This serves to highlight innovations with a universal application, control for the difference in the propensity to file multiple patent applications for a single invention between patent offices and exclude singletons of possible low value while including high-value domestic inventions.[4]

Analysis of international patent families (IPFs) from 2014 to 2023 provides insights into innovation across the four principal transport modalities of Land, Sea, Air, and Space (Figure 3.16). Each domain exhibits unique characteristics in terms of the number of IPFs, inventor locations and key patent owners, reflecting technological advancements and competitive dynamics.

4 Dechezleprêtre, A., Y. Ménière and M. Mohnen (2017). International patent families: From application strategies to statistical indicators. Scientometrics, 111, 793–828. DOI: https://doi.org/10.1007/s11192-017-2311-4.

Extending patent protection beyond domestic borders highlights the importance of a more global patent strategy for many locations

Figure 3.16 Exploring international patent families in the four transport modalities, 2014–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The Land domain leads with almost 225,000 IPFs, which highlights the global importance of innovation in road and rail transport technologies. For Land transportation, Japan leads with 29% of IPFs, followed by the United States (23%), the Republic of Korea (16%), China (15%), and Germany (13%), reflecting strong innovation in these locations. In terms of international focus, Sweden stands out, with 93% of its Land transport patents being IPFs, followed by the United Kingdom (81%), Canada (75%), and France and India (both 71%), indicating a strong emphasis on global protection compared to the global IPF average of 34% in Land transport. Leading companies such as Toyota, Hyundai Motor and Ford Motor are at the forefront, emphasizing the focus on sustainable and advanced vehicle technologies.

In the Sea domain, there are over 7,500 IPFs. In Sea transportation, the United States dominates in the number of IPFs, with 19% of IPFs, while Japan (17%), the Repubic of Korea (13%), China (11%), and France (10%) follow. Norway leads in international share, with 90% of its Sea patents being IPFs, trailed by Australia (85%), France (83%), the United Kingdom (78%) and Italy (73%), showing significant international activity. Patents from these locations far exceed the global IPF average of 22% in Sea transport. Key players include Gaztransport and Technigaz and Mitsubishi Heavy Industries, reflecting an emphasis on maritime technologies like shipbuilding and ocean exploration.

The Air domain is marked by almost 36,000 IPFs. Again, the United States takes the largest share, with 42% of IPFs, while China (14%), France (11%), Japan (11%) and Germany (9%) are also major contributors. Australia has the highest international share at 87%, followed by the United Kingdom (83%), Canada (81%), India (77%) and France (74%), which can be compared to the global IPF average of 35% in Air transport. RTX and General Electric lead the sector, indicative of intense research and development (R&D) in areas like propulsion systems and avionics. The concentration of IPFs among top firms points to the significant capital and expertise required to innovate in aerospace and the strategic importance of maintaining technological leadership.

For Space transport, with its almost 14,000 IPFs, the United States leads with a 37% global share, followed by China (24%), Japan (13%), Germany and the Republic of Korea (both 7%). Sweden stands out with 96% of its Space patents being IPFs, while the United Kingdom (85%), France (84%), Germany (81%) and Canada (76%) also prioritize global patent protection within this sector, compared to the global IPF average of 25% in Space transport. Huawei and Lenovo are key players, reflecting the growing intersection of telecommunications and aerospace technologies.

Based on the total future transport IPFs counts for each inventor location from 2014 to 2023, the United States holds the highest count with 73,864 IPFs, followed by Japan (71,073). China comes in third with 42,944 IPFs, while the Republic of Korea has 38,439 IPFs. Germany ranks fifth with 34,711 IPFs, followed by France (12,848), the United Kingdom (8,599), Canada (5,255), India (4,396) and Sweden (3,866) rounding off the top 10 inventor locations.

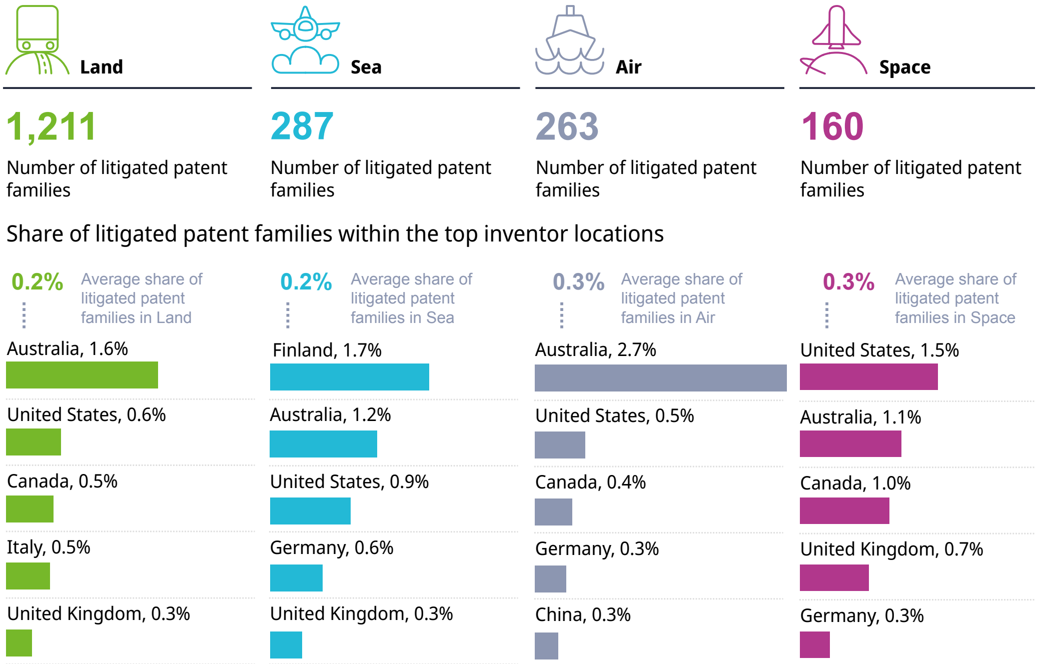
Overall, the IPF analysis highlights how each of the four principal transport modalities reflects different innovation dynamics and industry focus. The Land domain's vast number of IPFs points to widespread global innovation, whereas the Air domain has the highest global share of IPFs, highlighting its strategic importance and the high stakes of aviation advancements. The Sea and Space domains, though smaller in terms of number of IPFs, reveal specialized and critical areas of technological development.

Patent litigation in transportation

The landscape of patent litigation varies significantly across the different modalities in the future transportation sector, with notable differences in volumes of litigation, litigation ratios, and inventor locations. Analysis of patent dispute data, shown in Figure 3.17, highlights key trends and patterns in patent litigation.

The rate of patent disputes is largely the same across all four transport modalities, but there is a higher chance of patent litigation in Australia and the United States of America

Figure 3.17 Exploring litigated patent families in the four transport modalities, 2014–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

In the Land transport modality, patent litigation activity reveals a competitive landscape in road and rail technologies. China leads in terms of litigated patents, with 514 cases, closely followed by the United States with 466. Other inventor locations with significant volumes include Japan and Germany, and there is a strong automotive industry in all of these locations. Although China has a higher volume of litigated patents, the United States demonstrates a greater litigation ratio of 0.6%, compared to China's 0.2%, reflecting a more active approach to legal enforcement. Australia has the highest litigation rate, with 1.6% of all Land transport patents in Australia resulting in dispute, far above the global average of 0.2%.

In Sea transport, China leads in litigated patents, with 35 cases, followed by the United States at 23, which reflects China's expansive research and development efforts in maritime technology. Sea transport also has an average litigation rate of 0.2% globally, with the highest share of litigated patents in Sea transport seen in Finland (1.7%), Australia (1.2%) and the United States (0.9%).

In the Air transport modality, the litigation ratio is slightly higher at 0.3%, with Australia having a significant litigation ratio of 2.7%, which underscores a proactive stance on patent enforcement relative to its patents in Air transport. China holds the highest volume of litigated patents with 126 cases, followed closely by the United States at 125.

In Space transport, the litigation ratio is also 0.3%, comparable to that of the Air modality and indicating a similarly high level of patent disputes. The United States is a dominant contributor, with 133 litigated patents, followed by China with 37. Again, the United States and Australia both have a larger share of Space transport in dispute that the global average, and substantially higher litigation ratios than the global average are also seen in Canada and the United Kingdom.

Beyond patents – exploring transportation trademarks

Trademarks are crucial within the transportation sector because they establish brand recognition, build trust and differentiate between companies in a highly competitive market. In transportation, safety, reliability and efficiency are top priorities, and a recognizable trademark and a strong brand can signal quality and dependability to customers. For instance, when people see well-known logos from transportation brands such as Toyota, Uber or Lufthansa, they immediately associate them with a certain standard of service or product quality, which can influence their choices.

Trademarks also help protect a company's reputation by preventing others from imitating their brand or misleading customers. In a field where companies invest heavily in developing technology and customer service standards, trademarks provide legal grounds to defend their brand identity. As transportation companies expand internationally, strong trademark protection can ensure that brand recognition and trustworthiness carry over to new markets, enhancing customer loyalty and brand equity on a global scale.

By looking beyond just patents and exploring global trademark data, we can see that from 2004 to 2023, trademark filings in Goods (vehicles and vehicle parts, class 12 in Nice classification) and Services (transportation services, class 39 in Nice classification [5]) have shown a consistent increase, reflecting the growing importance of brand protection across these sectors (Figure 3.18). The compound annual growth rate (CAGR) for Goods reached 5.6%, while Services recorded a CAGR of 6.0%. The combined growth rate of 5.8% signifies a steady expansion in trademark activity during this period, driven by an increasing emphasis on establishing and protecting brand identities within the automotive and transportation industries.

5 See, Nice classification, available at: www.wipo.int/classifications/nice/en.

A snapshot of the trademark landscape in the transportation sector, highlighting historical filing trends, key locations and top filers

Figure 3.18 Exploring trademarks in the transportation sector, 2004–2023

Total number of trademarks in transportation **3,725,444**

Goods Number of trademarks related to transportation goods

Number of trademarks related to transportation services **Services**

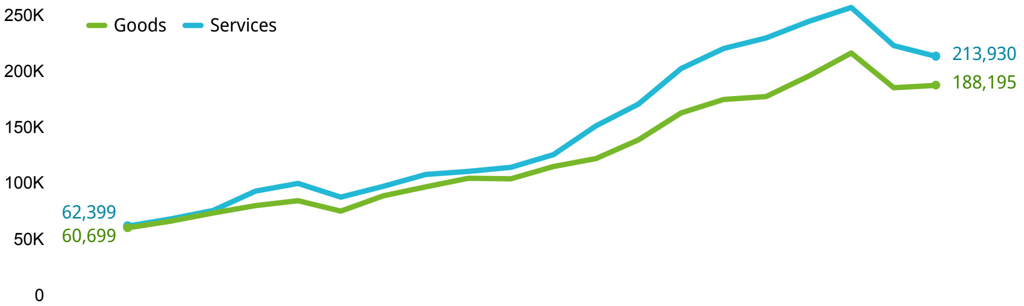
45%
Share of trademarks related to transportation goods

55%
Share of trademarks related to transportation services

1,681,429
Number of trademarks related to transportation goods

2,044,015
Number of trademarks related to transportation services

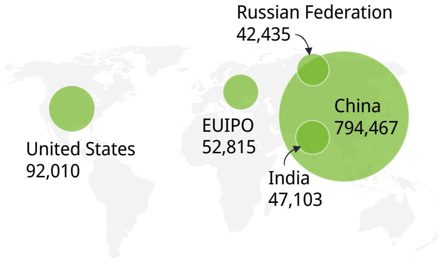
Filing trends of trademarks related to transportation



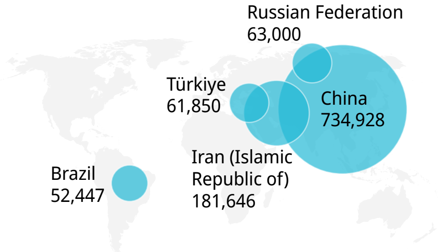
Top filing jurisdictions of trademarks related to transportation

Number of trademarks

Goods



Services



Top filers of trademarks related to transportation

Goods

Toyota Jidosha Kabushiki Kaisha
6,274

Kia
5,912

Hyundai Motor Company
5,520

General Motors
4,752

Mercedes-Benz Group
4,304

Services

Beijing Jingdong Triple Bai Lu Pick Up of E-Commerce
1,975

American Airlines
1,622

Amazon Technologies
1,494

Alibaba Group Holding Limited
1,415

Enterprise Holdings
1,085

Top neighbor classes to transportation trademarks

Goods
Scientific Instruments

Services
Advertisement and Business Methods

Source: WIPO, based on trademark data from Clarivate, September 2024.

However, a notable shift has occurred in the more recent period from 2018 to 2023, when growth rates slowed considerably. Filings for Goods experienced a modest growth rate of 1.4%, whereas Services saw a slight decline, with a CAGR of –0.6%. This resulted in an overall modest growth rate of only 0.3% for Goods and Services combined. This apparent slowdown in trademark activity may be attributed to various factors, including the lingering impact of the COVID-19 pandemic and changes in business priorities influencing filing behavior across these classes.

The synchronized trends between Goods and Services suggest that both categories are similarly affected by broader market dynamics and economic conditions. External factors, such as economic cycles, industry shifts and consumer behavior, have likely contributed to the alignment of trends in trademark activity across these classes. The overall stability observed in trademark filings underscores the significant impact of prevailing economic conditions on brand protection efforts in the transportation sectors.

Geographically, China stands out as a dominant player in trademark filings for Goods, exhibiting a growth rate of almost 7.5%. Filings increased more than two-fold from 41,162 in 2014 to 85,438 in 2023, supported by China’s robust automotive industry and proactive trademark protection efforts. Despite a slight decline in filings after 2021, China's strong position in the market remains evident. Filings from the United States increased from 5,570 in 2014 to 11,751 in 2023, resulting in a very healthy CAGR of 8.9%. However, this growth has shown signs of slowing, with a CAGR of 7.4% from 2018 to 2023.

In the realm of Services, China again leads with a more than two-fold increase from 28,602 filings in 2014 to 70,411 in 2023 (CAGR of 10.1%). Other noteworthy contributors include the Islamic Republic of Iran, whose filings rose from 8,631 to 17,053 during the period, and Brazil, which has seen a CAGR of 10.9% and reaching 9,446 filings in 2023.

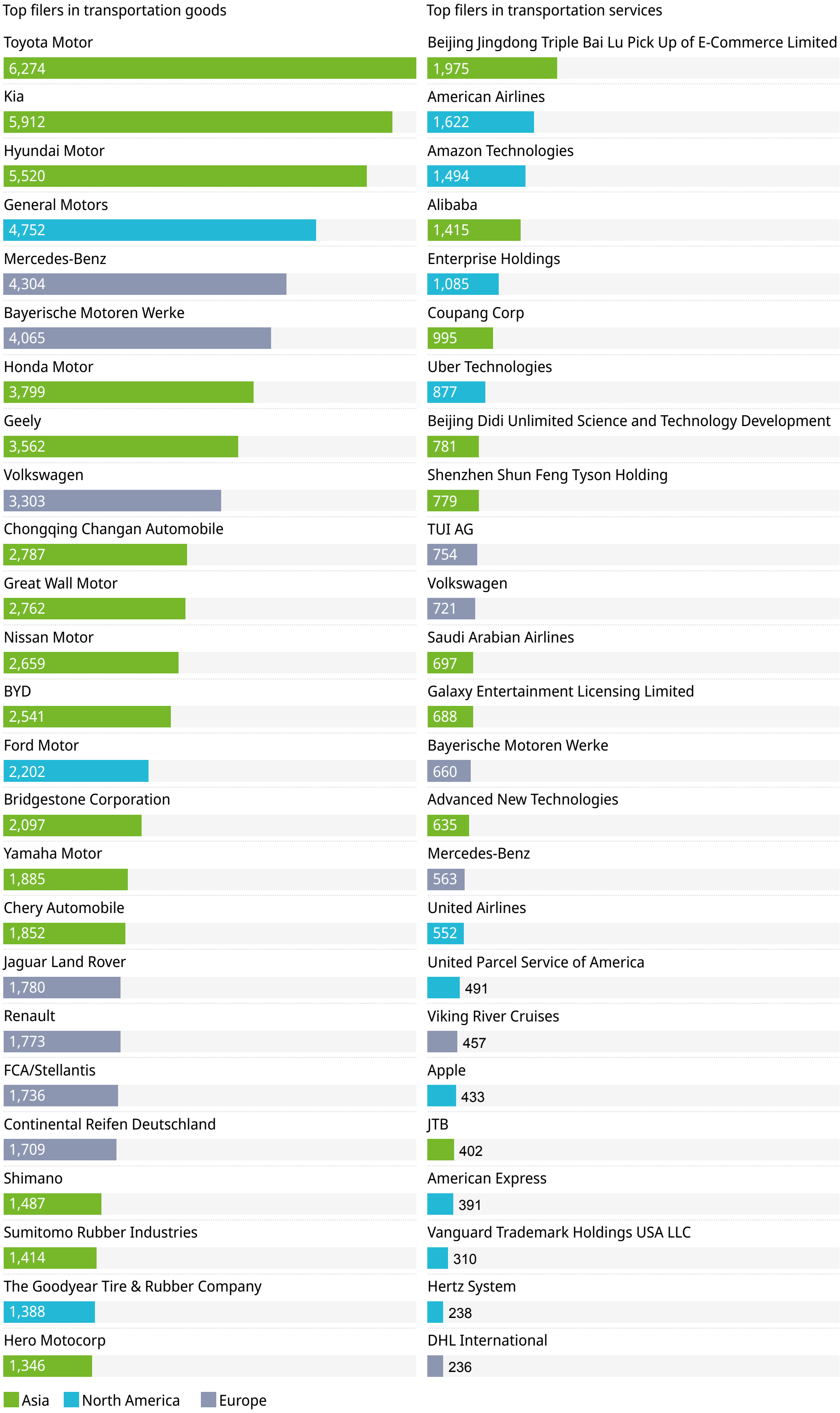
Overall, the analysis of trademark filings in Goods and Services from 2014 to 2023 reveals a dynamic landscape characterized by growth trends influenced by regional players and market shifts. While established markets like China, the United States, and the European Union (EU) maintained a strong position, emerging markets such as Brazil, the Islamic Republic of Iran, the Russian Federation and Türkiye are increasingly making their mark, contributing to a more competitive environment in trademark activity.

Prominent players within the automotive sector have also contributed to these filing trends (Figure 3.19). In transportation Goods, Asian giants Toyota, Kia and Hyundai lead the way, whereas trademarks in transportation Services are led by Beijing Jingdong Triple Bai Lu, American Airlines and Amazon.

More broadly among the top 25 trademark filers in transportation Goods and Services, there is an interesting difference between the two lists. In transportation Goods, the biggest trademark portfolios belong to large automotive manufacturers such as General Motors, BMW, Jaguar Land Rover and BYD, and suppliers, such as the tire companies Bridgestone and Goodyear, and parts companies like Shimano. In contrast, the biggest trademark portfolios in transportation Services include a broader range of industries within the transportation sector – the list includes airlines such as Saudi Arabian Airlines and United Airlines, e-commerce companies like Alibaba, logistic companies, such as UPS and DHL, and travel companies including Uber, TUI and Hertz, as well as technology companies like Apple and finance companies like American Express.

Trademarks for goods are dominated by dominated by the large automotive manufacturers, whereas trademarks for services feature a diverse range of aviation, e-commerce, logistics and travel companies

Figure 3.19 Top 25 trademark filers in transportation, 2014–2023



Source: WIPO, based on trademark data from Clarivate, September 2024.

Beyond patents – industrial designs within the transportation sector

Industrial designs are also important within the transportation sector because they enhance both functionality and customer appeal, providing a competitive edge in a market where aesthetics, ergonomics and user experience are increasingly valued. An industrial design covers the visual aspects of a product – its shape, lines, patterns and overall look – elements that strongly influence consumer perception and satisfaction.

In the automotive industry, for example, a well-designed car is not just visually appealing; it often reflects brand identity, safety and innovation. Companies like Tesla and BMW use distinct designs to communicate values like performance, luxury or sustainability, helping them stand out in a crowded market.[6] Similarly, in public transport, the design of buses, trains and even airline interiors can influence passengers' comfort and convenience, which affects ridership and user satisfaction.

Industrial designs also protect companies' investments by giving them exclusive rights to unique visual features, preventing competitors from copying their look and feel. This ensures that innovations in design contribute to brand identity and market differentiation, making industrial design a valuable asset within the transportation sector.

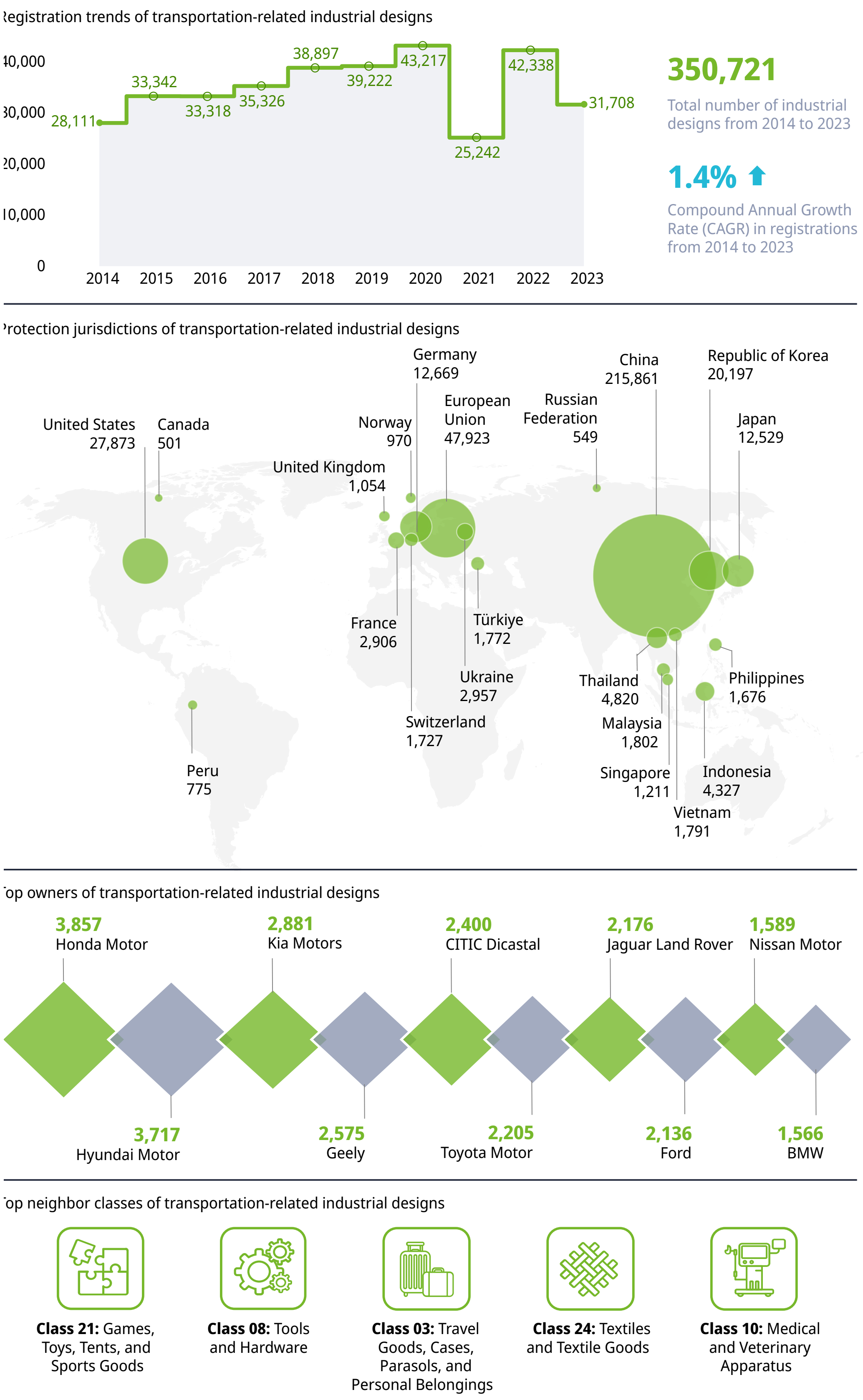
By analyzing industrial designs in transportation (Locarno class 12), which includes vehicle-related designs across Land, Sea, Air, Space and others.[7] Figure 3.20 shows a fluctuation in design registrations over the past decade. Registrations increased from approximately 28,000 in 2014 to almost 32,000 in 2023, peaking in 2020 at over 43,000 registrations. However, the 2020 peak was followed by a decline in 2021, possibly due to the effects of the COVID-19 pandemic. Another dip was seen in 2023, possibly indicating a recent shift in industry focus, although this is too early to confirm.

6 See www.wipo.int/web/ip-advantage/w/stories/hague-system/ji-yue-redefining-electric-vehicle-design-with-ai-innovation for a design-meets-innovation story about JI YUE, which uses a user-centric design approach to lead the way in pioneering, sustainable mobility solutions.

7 See, Locarno classification, available at: www.wipo.int/classifications/locarno/en.

A snapshot of the industrial design landscape in the transportation sector, highlighting historical filing trends, key locations and top filers

Figure 3.20 Exploring industrial designs in transportation, 2014–2023



Source: WIPO, based on industrial design data from the WIPO Global Design Database, October 2024.

Locations with dominant automotive industries lead the registrations, such as China, the United States, the Republic of Korea and Japan at the forefront. Japanese giant Honda is the top owner (3,857 registrations), followed by Hyundai (3,717) and Kia (2,881), both from the Republic of Korea, showcasing their strength in the global automotive market. Geely (2,575), a leading Chinese automotive manufacturer, and CITIC Dicastal (2,400), a leading Chinese manufacturer of automotive parts, are also significant players, reflecting the rapid growth of its domestic automotive industry.

Traditional Western companies like Ford and Jaguar Land Rover maintain prominence with over 2,100 combined registrations each. Strong recent growth is also seen from companies such as BYD (not shown in Figure 3.20) with 532 filings, who are becoming increasingly prominent players in global vehicle design, especially in electric vehicles.

Neighboring classes, particularly Class 21 (furniture and articles not classified elsewhere) and Class 8 (hand tools and implements), have seen parallel growth. The relationship between these classes and industrial designs in transportation is often driven by innovations in vehicle interiors and ergonomics, influenced by furniture design principles.

Beyond patents – insights into market, regulatory, and economic landscapes

Several critical dimensions that extend beyond the realm of intellectual property have also been explored. While patents offer valuable insights into technological innovation, understanding the broader market, regulatory frameworks, and economic conditions is essential for a comprehensive analysis.

The global transportation industry market (Figure 3.21) reached USD 7.3 trillion in 2022 and is projected to grow to USD 11.1 trillion by 2030, with an expected CAGR of 5.4% from 2023 to 2030.[8] Asia-Pacific holds the largest and fastest-growing market share, driven by urbanization, population growth and significant investments in transportation infrastructure, particularly in China and India. Market dynamics are heavily influenced by the rise of e-commerce, technological advancements in automation and autonomous vehicles, and regulatory challenges.

Collaboration needed for faster progress in transportation standards – Robert Garbett, Drone Major Group

Standards are critically important. And before you start delving into technical standards, you need to be looking at the safety and quality standards that already exist.

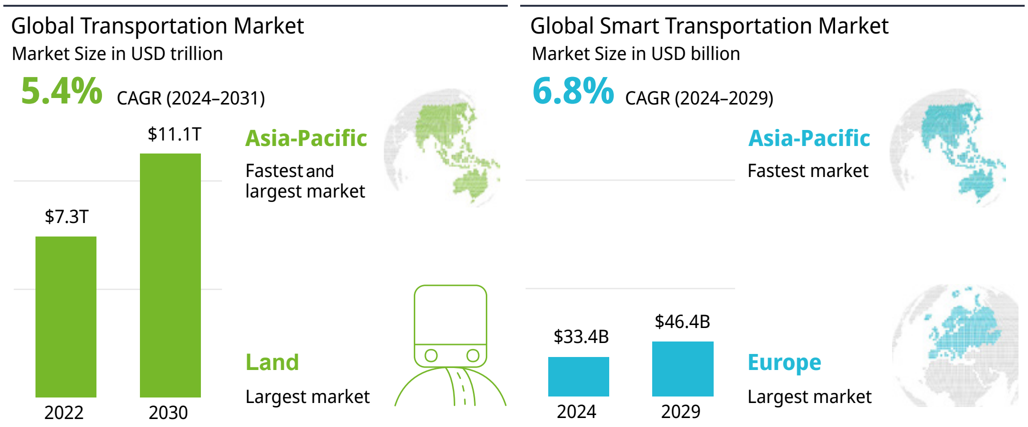
We must have more companies engaged in the development of standards. It is to their benefit and it is to the industry's benefit. And we will get to where they want to get to faster as a result.

Land transportation has emerged as the highest-growing segment, covering over 42.3% of the market in 2022. Key players include DHL, BlueDart and C.H. Robinson Worldwide. The COVID-19 pandemic caused a substantial disruption to transportation services and global supply chains, while recent geopolitical conflicts have complicated trade dynamics and maritime logistics. Recent developments highlight strategic alliances and technology integrations, such as the partnership between Flexport and Nolan Transportation Group and MercuryGate International's smart transportation capabilities.

8 Data Intelligence (2014). Transportation industry market size. Available at: www.datamintelligence.com/research-report/transportation-industry-market.

The global transportation market is a multi-trillion dollar industry, with smart transportation a growing part of the industry

Figure 3.21 Global transportation and smart transportation market



Source: WIPO, based on market data from Datam Intelligence and Mordor Intelligence, October 2024.

The smart transportation market is poised for significant growth, with its size estimated at USD 33.4 billion in 2024 and expected to reach USD 46.4 billion by 2029, growing at a CAGR of 6.8% during the forecast period.[9] Considering these studies, global smart transportation accounts for approximately 0.5% of the global transportation market. Asia-Pacific is projected to register the fastest growth, while Europe holds the largest market share. Key market drivers include increasing traffic volume, government initiatives to reduce greenhouse gas emissions, urbanization, and the rise of megacities. Technological advancements like IoT and AI are pivotal in developing smart transportation solutions, including autonomous vehicles and intelligent traffic management systems.

The COVID-19 pandemic has accelerated the adoption of contactless and sensor- based technologies in public transit. Major players such as Cisco, SAP SE, IBM and Siemens are focusing on expanding operations and developing innovative solutions. Recent developments include projects and collaborations aimed at enhancing smart transportation infrastructure and integrating advanced technologies.

CERN's collaborative approach to bringing disruptive technologies to sustainable mobility – Manuela Cirilli, CERN

The future of transportation is poised for significant transformation, driven by the need for more sustainable, efficient and accessible mobility solutions. As in other fields, disruptive technologies hold promise to be game-changers but their widespread adoption is often challenging. Besides the technical hurdles in reaching full maturity, these technologies can have high initial costs as well as require significant infrastructure investment and an evolution in regulatory frameworks.

At CERN, the European Laboratory for Particle Physics, we are not only at the forefront of fundamental research, but also the development of the cutting-edge technologies needed to realize our scientific ambitions. Further, we are eager for our technologies to be at the heart of impactful societal innovations. The most well-known example of a CERN technology that has revolutionized our lives is probably the World Wide Web, but we are making significant contributions to other areas, including medical imaging, cancer treatment, cultural heritage, space missions, environmental applications, as well as the future of transportation.

When the conditions are right, exciting developments can happen. An example is CERN's collaboration with Airbus UpNext, a subsidiary of Airbus, to explore the use of superconducting

9 Mordor Intelligence (2024). Smart Transportation Market Size and Share Analysis: Growth Trends and Forecasts (2024–2029). Available at: www.mordorintelligence.com/industry-reports/smart-transportation-market.

technologies in future hydrogen-powered aircraft. With SuperNode, a developer of energy transmission technology based on superconductivity, we are developing a novel type of insulation for superconducting cables with the aim of improving energy infrastructures and accelerating the transition to renewable energy. Artificial intelligence and machine learning can also be critical enabling technologies, and we have worked with Zenseact, a car-safety software company founded by Volvo Cars, on enhancing the speed and accuracy of decision-making in self-driving cars through improved deep-learning algorithms.

We are regularly confronted with the challenges of bringing disruptive technologies from a physics laboratory onto the market, especially when we deal with deep tech and “extreme” settings – superconductivity, superfluidity, cryogenic temperatures. We extend the lessons learned from the highly collaborative nature of particle physics research to our innovation partnerships and intellectual property policy: for example, we might choose a patent strategy or an open dissemination policy, depending on which choice maximizes the value of our technology for industry. The adoption by industry of technologies released under the CERN Open Hardware Licence is a great demonstration that there is no one-size-fits-all approach. The future of transportation will also be shaped by pioneering partnerships between research institutes and industry, and we should strive to catalyze more of these ventures: together, public research and the private sector can drive innovation more effectively than on their own.

The future of transportation is poised for significant transformation, driven by the need for more sustainable, efficient and accessible mobility solutions. As in other fields, disruptive technologies hold promise to be game-changers. But their widespread adoption is often challenging. Besides the technical hurdles in reaching full maturity, these technologies can have high initial costs and require significant infrastructure investment and an evolution in regulatory frameworks.

Governments worldwide actively promote sustainable transportation through a range of policies and programs. Such initiatives aim to reduce emissions, enhance mobility and improve infrastructure. Many places offer fiscal incentives for EV adoption, including purchase subsidies and tax rebates, as seen in China, Norway and the United States.[10] Government agencies support exporters and importers through services like market research and logistics assistance, facilitating international trade. Economic recovery packages, including vehicle scrappage and purchase bonuses, support sales and jobs within the transport sector. In the United States, the Bipartisan Infrastructure Law (BIL) allocates substantial funding for transportation infrastructure, covering roads, bridges, public transit, rail, ports, and EV charging infrastructure.[11] The Federal Lands Access Program (FLAP) supports transportation projects on US federal land, improving access to national parks, forests, and wildlife refuges.[12] The UN-led Partnership for Electric Mobility accelerates the shift toward electric mobility in 27 countries, focusing on policy development, infrastructure deployment, and capacity building.[13]

The regulatory landscape is intrinsically linked to the transportation sector and can have a big impact on innovation in transportation technologies. Regulatory Impact Analysis (RIA) by the Organisation for Economic Cooperation and Development (OECD) assesses the costs, benefits, and potential impacts of regulatory changes, essential for shaping transport policies.[14] The European Union sets stringent emission standards for road transport, ships, and combustion machinery, aiming to improve air quality and mitigate climate change. Investments in public transportation, cycling infrastructure, and alternative energy sources contribute to a sustainable transport system.[15]

10 EcoMotionCentral (2023). Electric vehicle incentives around the world: A comparative analysis. Available at: ecomotioncentral.com/electric-vehicle-incentives-around-the-world-a-comparative-analysis
11 U.S. Department of Transportation. Bipartisan Infrastructure Law. Available at: www.transportation.gov/bipartisan-infrastructure-law.
12 Federal Highway Administration. Federal Lands Access Program (FLAP). Available at: https://highways.dot.gov/federal-lands/flap.
13 GEF (2021). UN-led partnership to accelerate electric mobility shift in 27 countries. Global Environment Facility. Available at: www.thegef.org/newsroom/press-releases/un-led-partnership-accelerate-electric-mobility-shift-27-countries.
14 OECD (2009). Regulatory Impact Analysis: A Tool for Policy Coherence, OECD Reviews of Regulatory Reform. Paris: OECD Publishing. Available at: www.oecd.org/en/publications/regulatory-impact-analysis_9789264067110-en.html.
15 European Commission. Road transport: Reducing CO_2 emissions from vehicles. Available at: https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles_en.

The future of the transportation sector is defined by strategic policies addressing increasing global transport demand and CO_2 emissions. The ITF Transport Outlook predicts, under the Current Ambition scenario, a 79% increase in passenger demand and a doubling of freight demand by 2050, while the High Ambition scenario forecasts a 65% rise in passenger demand and a 59% increase in freight demand.[16] In the United Kingdom, the Future of Transport Programme aims to reduce emissions and improve air quality through innovations like EVs and drones, alongside modernized regulations.[17] Switzerland's Transport Outlook 2050 anticipates slower transport demand growth, influenced by remote work and urbanization trends. By 2050, Switzerland's transport sector is expected to see an 11% increase in overall transport, compared to a 21% population growth, and a 31% rise in freight transport, against a 57% GDP growth.[18] Comprehensive strategies, such as these, emphasize the importance of investment and innovative policies meeting future transport demand and mitigating environmental impacts.

Empowering innovators: how WIPO fosters growth and sustainable development

This data-rich report on the future of transportation forms part of the WIPO Technology Trends series, combines IP analysis, scientific literature, policy impacts and expert insights to guide business leaders, researchers, and policymakers in making informed decisions.

But WIPO's support goes beyond providing reports. We empower local researchers, innovators, universities and research institutions in unlocking the full potential of intellectual property (IP), maximizing its impact on their ventures. By collaborating with stakeholders such as these, we at WIPO build, nurture and strengthen local innovation ecosystems, expanding their reach through national, regional and international networks.

To leverage IP as a tool for growth and sustainable development, WIPO offers support from the first spark of an idea and onward through its journey to market. WIPO provides services and amplifier programs that include, among others, IP information, improved access to the patent system, support for more effective IP rights management, facilitate more efficient technology transfer, and support for the use of IP as a financial asset. These services are underpinned by capacity building for individuals and institutions.

WIPO helps innovators leverage IP as a tool for growth and sustainable development. Our support for innovators includes:

- **Capacity building** through programs directed at upskilling actors in the innovation ecosystem to effectively use the IP system, technological information and the knowledge to be found in patent and scientific and technical literature databases; and to manage IP from creation to the commercialization of products and services based on research outcomes.[19] [20] [21]
- **Resources, tools, and platforms** that deliver insights, information and facilitate cost-effective interactions[22]
- **Networking opportunities** that enable sharing of experiences and best practice
- **Thought leadership** that facilitates global coordination in inclusive international technology transfer, IP analytics, and IP finance.[23] [24] [25]

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16 International Transport Federation (2023). ITF Transport Outlook 2023. Paris: OECD Publishing. Available at: www.itf-oecd.org/sites/default/files/repositories/itf-transport-outlook-2023-summary-en.pdf.
17 Department for Transport (2020). Future of Transport programme. Available at: www.gov.uk/government/collections/future-of-transport-programme.
18 ARE (2022). Transport Outlook 2050. Federal Office for Spatial Development ARE. Available at: www.are.admin.ch/are/en/home/mobility/data/transport-outlook.html.
19 WIPO’s Technology and Innovation Support Center (TISC) program gives innovators in developing countries access to high quality technology information and related services to help them create, protect, and manage intellectual property rights. Our 1500 TISCs in 93 countries have handled over 7.5 million inquiries in the past four years.
20 WIPO's Inventor Assistance Program matches developing country inventors and small businesses with limited financial means with patent attorneys, who provide pro bono legal assistance to secure patent protection.
21 The WIPO Patent Drafting Training Program assists users of the patent system to develop practical skills in drafting and filing patent applications.
22 WIPO INSPIRE (https://inspire.wipo.int/) is a global knowledge center for innovation, helping innovators and entrepreneurs make informed decisions throughout the innovation cycle. It provides a unique blend of information and knowledge on patent search, patent analytics, technology transfer, and institutional IP policies, combining reference data with expert insights into resources, tools, and good practice recommendations.
23 WIPO. Intellectual property and technology transfer. Available at: www.wipo.int/web/technology-transfer.
24 WIPO. Patent analytics. Available at: www.wipo.int/en/web/patent-analytics/index.
25 WIPO. Intellectual property finance. Available at: www.wipo.int/web/ip-financing.

4 Exploring transport modalities

This chapter provides an overview of the global patent landscapes relating to the four principal transport modalities discussed – Land, Sea, Air and Space. A more detailed deep-dive analysis of each of modality can be found in the four technical annexes that accompany this report.

Land transportation

Land transportation, encompassing the movement of people, goods and animals via road and rail networks, plays a crucial role in global trade and mobility, influencing economic development and environmental sustainability. Freight activity is projected to grow significantly, with worldwide ton-kilometers nearly doubling between 2019 and 2050. Despite this growth, CO_2 emissions from passenger transport are projected to decrease, especially under the International Transport Forum's (ITF) High Ambition scenario.[1] Efforts to decarbonize the transport sector are critical for reducing emissions and achieving sustainable mobility.

Sustainability and Digitalization are key trends transforming Land transport. Sustainability drives innovation toward reducing CO_2 emissions and promoting greener practices, while Digitalization enhances operational efficiency through advancements in technology and data analytics. The transport sector accounts for nearly one-quarter of global energy-related CO_2 emissions, with road travel responsible for approximately 75% of transport emissions. Ambitious policies and technologies like zero-emission vehicles (ZEVs) and efficiency technologies are crucial for reducing emissions.

Are autonomous vehicles really safer than a car driven by a human? – Robert Garbett, Drone Major Group

An unmanned vehicle certified with the right level of software and the right infrastructure around it is absolutely safer than a manned vehicle – provided that every vehicle on the road or every vehicle that is able to interact with that vehicle is also unmanned. As soon as you've got other drivers on the road who are humans, you have huge problems.

We are going to see more intelligence and autonomy appearing in cars. It makes driving far safer and far more relaxing but true, wide scale autonomy, is some way off and will require the majority of vehicles to be autonomously capable and, even when we get to that stage, you're going to have a driver sitting in there who will have to take responsibility for that vehicle, unless you're in a dedicated lane or you're in a dedicated area where everyone knows the vehicles are all autonomous and there's probably no driverless vehicles around, say for instance, a university campus or an airport.

1 International Transport Federation (2023). ITF Transport Outlook 2023. Paris: OECD Publishing. Available at: www.itf-oecd.org/sites/default/files/repositories/itf-transport-outlook-2023-summary-en.pdf.

Digitalization is revolutionizing Land transport by driving significant advancements in efficiency, safety and customer experience. Key drivers include substantial increases in investment in technology – particularly post-COVID-19 pandemic – and the integration of AI into navigation systems. Sensor technologies enhance safety and efficiency, while cloud computing and low-latency internet are revolutionizing data management and utilization. However, as Land transport becomes more digitalized, cybersecurity has become of paramount concern.

Emerging economies lead the way in urban mobility solutions – Tom Standage, The Economist

Different business models are appearing across the world. An interesting business model in Taiwan for recharging batteries is pavement kiosks – you pull out the batteries from your scooter and replace them with fully charged batteries from the kiosk, while your dead batteries go into the kiosk for recharging. This has created an influential monopoly and now even established scooter and motorbike manufacturers are conforming to this standard. If you live in a very urbanized place like Taiwan, you don't have on-street parking and don't have to have a garage where you can plug in. A lot of people are using scooters and this business model allows you to recharge them very, very quickly. Meanwhile there's a boom going on in electric three-wheelers in the Philippines, and electric motorbike-taxis in Kenya. I've always thought keeping an eye on what emerging economies are doing is very important, and not solely focusing on what's happening in the West.

Sustainable Propulsion technologies are transforming both passenger and freight transportation. Battery electric vehicles (BEVs) offer zero tailpipe emissions and lower operating costs, while hydrogen fuel cell electric vehicles (FCEVs) are proving promising for long distances and heavy-duty applications. E-fuels, or synthetic fuels, provide a drop-in solution for reducing greenhouse gas emissions without requiring extensive new infrastructure.[2]

Communication and Security technologies are paving the way for a new era of Land transportation. Advanced navigation systems leverage GPS technology, real-time traffic data and advanced routing algorithms to optimize travel routes, reduce travel times and improve fuel efficiency. Sensor technologies enhance safety and efficiency, while the adoption of cloud computing and low-latency internet is revolutionizing data management and utilization. Cybersecurity is essential for protecting transportation networks from cyber threats.

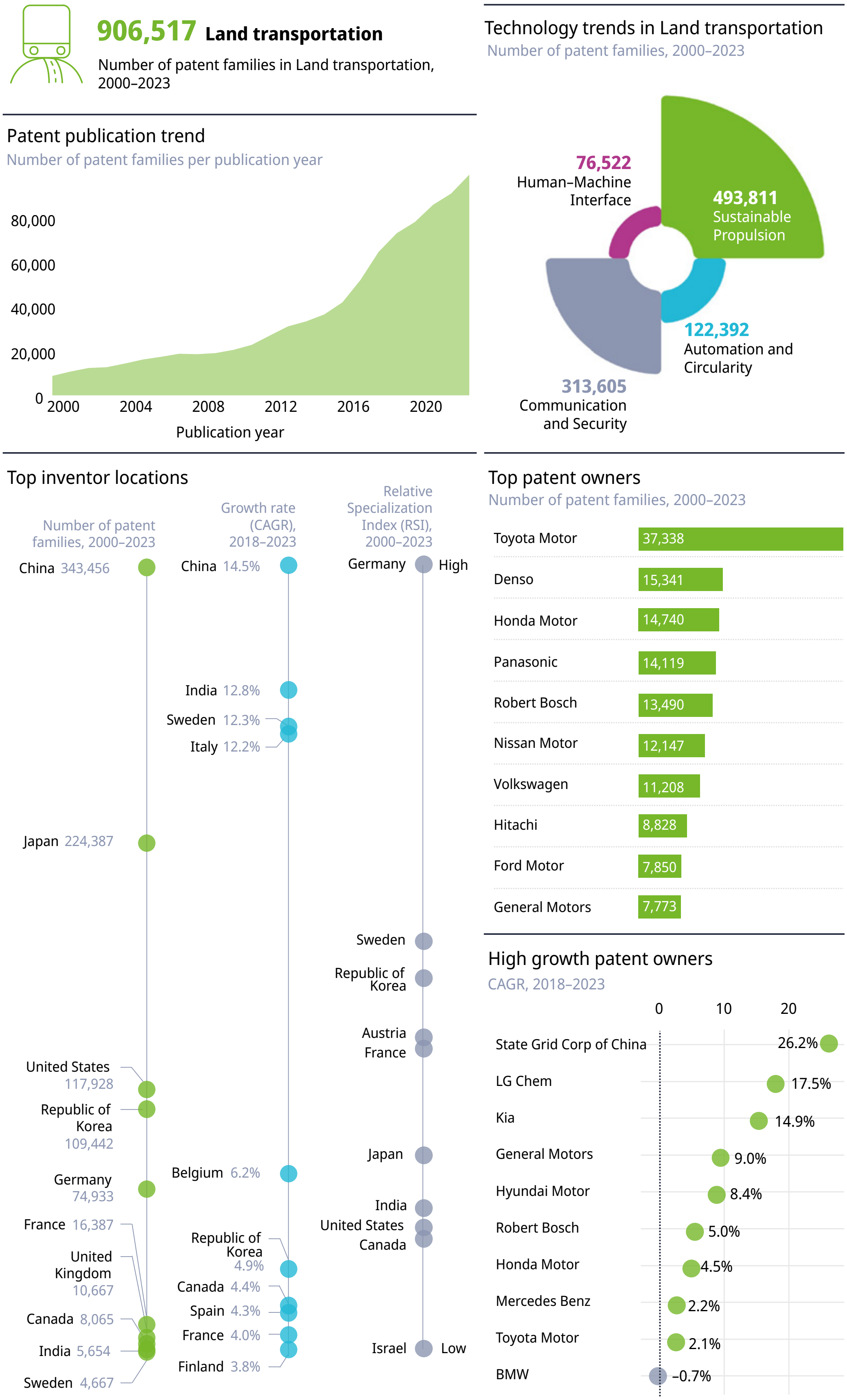
Automation and Circularity technologies are reshaping Land transportation by promoting efficient material use, smart production and enhanced recycling practices. Efficient material use involves adopting lightweight materials, utilizing advanced manufacturing techniques to reduce material waste and designing products for disassembly and recycling. Smart production and robotics are transforming manufacturing processes by enhancing efficiency, precision and flexibility. Recycling is a fundamental aspect of the circular economy, aiming to recover valuable materials from end-of-life products and reintroduce them into the production cycle.

Advanced Human–Machine Interfaces (HMIs) are also driving the evolution of Land transportation, by making interactions more intuitive, secure and responsive. Extended reality (XR) technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), are significantly enhancing HMIs. Speech recognition technology is transforming HMIs by enabling hands-free control and communication with vehicles and machines. Facial recognition technology enhances security and personalization, while touch displays and data gloves represent significant advancements in tactile HMIs.

2 The 2024 edition of the WIPO World Intellectual Property Report, with a focus on measuring innovation capabilities at the country level, features a case study on the motorcycle industry in Italy, Japan and India, and it analyzes the evolution of technological and production capabilities of motorcycle development – see https://www.wipo.int/en/web/world-ip-report/2024/index.

A snapshot of the patent landscape in Land transportation, highlighting historical patenting activity, technology trends, key locations and top filers.

Figure 4.1 Exploring the patent landscape in Land transportation



Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Hydrogen fuel is the future of long-haul trucking – Jason Schenker, Futurist

Hydrogen as a fuel is likely to be a better option for heavy-duty, long-haul vehicles rather than for personal vehicles that would require a much larger buildout of infrastructure. Long-haul trucks tend to move along certain transit corridors, which presents an opportunity to install hydrogen fuel at select locations for maximum impact and effect. This stands in stark contrast to consumer vehicle hydrogen use, which might very well require the installation of hydrogen fuel at virtually every gasoline station in the world.

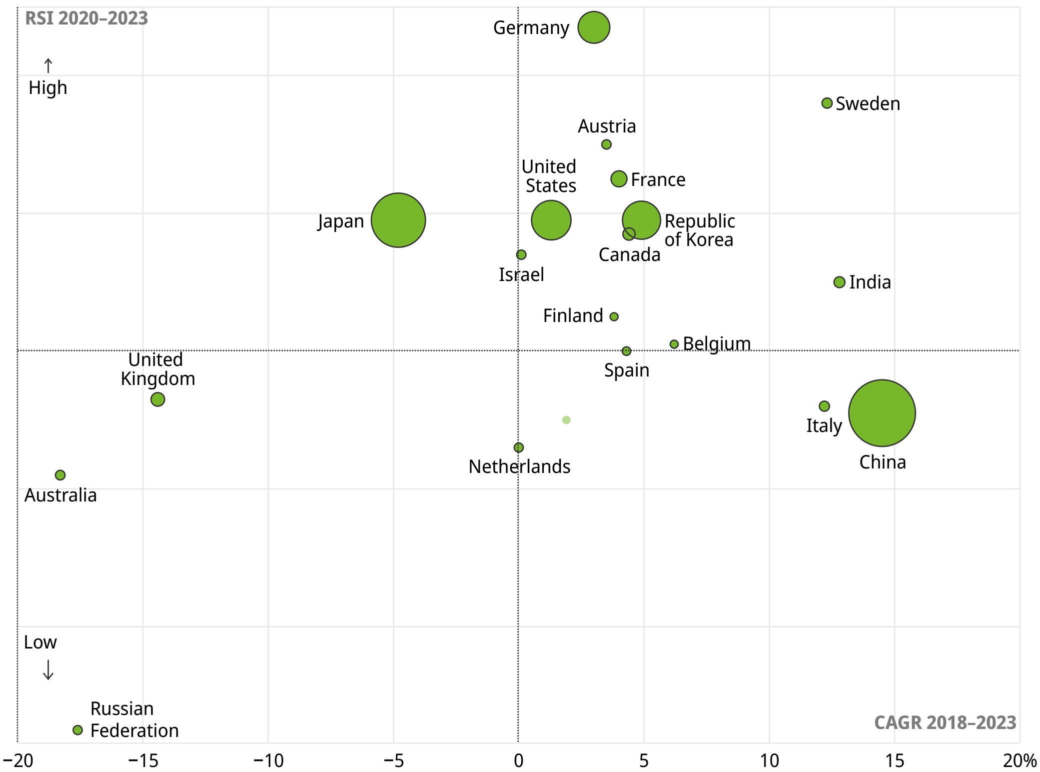
There are over 900,000 published patent families relating to Land transportation technologies (Figure 4.1). Patenting activity has increased significantly from around 8,800 in 2000 to over 99,500 in 2023, making it the largest among the four principal transport modalities in terms of number of patent families.

Land transportation patents primarily focus on Sustainable Propulsion and Communication and Security technologies, with the total number of inventions since 2000 reaching close to 500,000 and over 310,000, respectively. Patent families in Automation and Circularity and HMI technologies are comparatively fewer, but nonetheless the patenting compound annual growth rate (CAGR) is similar for all four technology trends, between 11% and 12%, since 2000.

Asia dominates in the patenting of Land transportation technologies, with over 690,000 inventions by Asian inventors since 2000, comprising over 76% of the total patent families in Land transportation. Europe and North America follow, with over 120,000 patent families each, making up over 13% of the total Land transport patents, respectively.

China and Japan lead global innovation in Land transportation technologies, while Germany and Sweden show high specialization and rapid growth is observed in China and India

Figure 4.2 Top 20 inventor locations in Land transportation: Number of patent families (2000– 2023), CAGR (2018–2023) and Relative Specialization Index (2020–2023)



Note: Circle size is proportional to number of published patent families.
Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

As shown in Figure 4.2, China and Japan have led global efforts in the research and development of Land transportation technologies, together comprising more than 60% of the global total. This is followed by the United States, Republic of Korea, and Germany. In terms of patenting growth rates, China and India have shown the fastest development since 2000, with a CAGR from 2018 to 2023 reaching 14% and 13%, respectively.

The top 20 inventor locations primarily focus on Sustainable Propulsion and Communication and Security technologies, although priorities vary by location. For instance, Israel focuses on Communication and Security technologies, whereas Austria, Japan and the Republic of Korea have a greater emphasis on Sustainable Propulsion. The Relative Specialization Index (RSI) indicates that the importance of research in Land transportation technologies has increased in nearly every major research location. According to the RSI, Germany is the most specialized location, highlighting its central role in the automotive industry. Sweden follows closely, with Austria, France, Japan, the Republic of Korea, and the United States also showing relative high specialization in this field.

Major patent owners in Land transportation are led by Japanese, German, and US companies, with Toyota leading the way by a distance

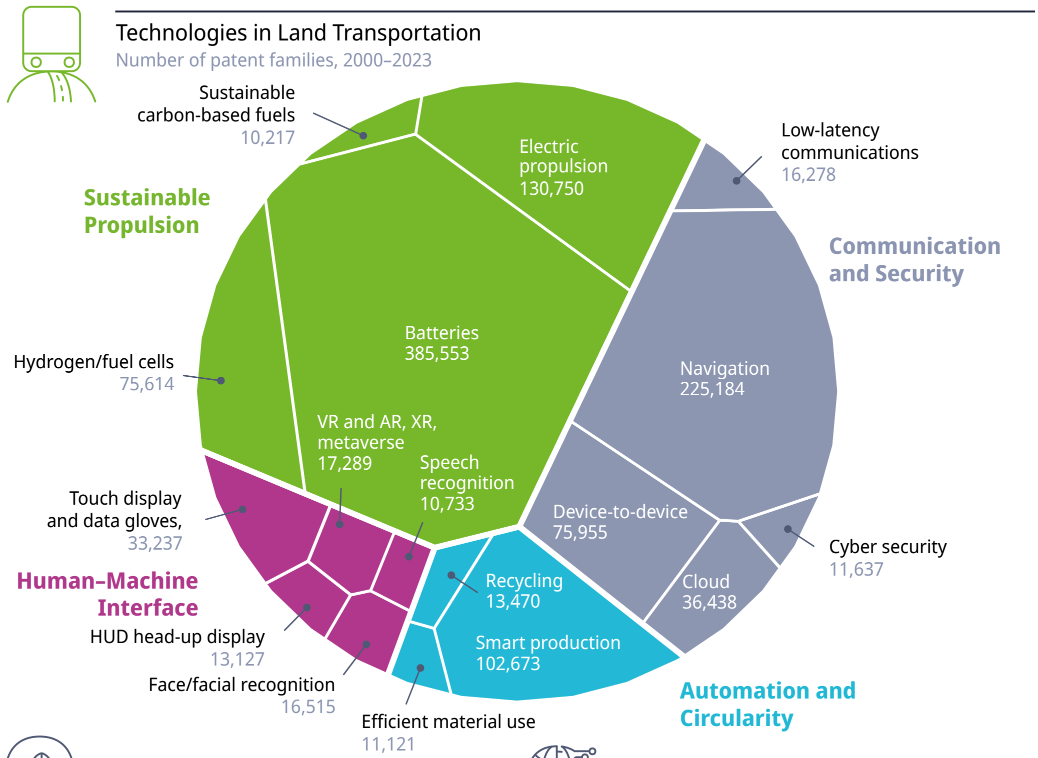
Figure 4.3 Top 25 patent owners in Land transportation: number of patent families by technology trends, 2000–2023

	Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Toyota Motor (Japan)	26,080	1,672	10,750	1,975
Panasonic Holdings (Japan)	9,491	542	3,921	1,371
Honda Motor (Japan)	8,737	1,274	5,152	1,197
Nissan Motor (Japan)	8,386	351	3,534	462
Bosch (Germany)	6,667	1,206	5,990	604
LG Chem (Republic of Korea)	6,154	131	25	33
Denso Corp (Japan)	5,961	525	8,204	2,941
Volkswagen (Germany)	5,106	568	4,677	1,828
Samsung SDI (Republic of Korea)	5,077	37	15	3
Hitachi (Japan)	4,730	1,339	3,245	385
Hyundai Motor (Republic of Korea)	4,442	673	2,597	733
General Motors (United States)	3,983	626	3,372	598
Toyota Industries (Japan)	3,936	103	413	32
State Grid Corp of China (China)	3,825	650	931	118
Ford Motor (United States)	3,783	614	3,786	753
Mercedes-Benz (Germany)	3,759	351	2,692	435
Kia Corp (Republic of Korea)	3,152	402	1,909	464
BMW (Germany)	2,957	353	2,230	778
Toshiba (Japan)	2,673	381	1,145	233
Aisin Corp (Japan)	2,465	91	2,538	1,021
Samsung Electronics (Republic of Korea)	2,142	562	4,279	1,409
Sony (Japan)	1,594	436	1,850	846
Mitsubishi Electric (Japan)	1,589	531	2,651	594
Valeo (France)	1,539	96	2,203	528
Continental (Germany)	851	272	3,075	454

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

A snapshot of the patent landscape in Land transportation in the four technology trends, highlighting key locations and top filers

Figure 4.4 Exploring the patent landscape in Land transportation in the four technology trends



Megatrend: Sustainability — Megatrend: Digitalization

Top inventor locations (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
China 185,790	China 61,609	China 110,495	China 21,233
Japan 138,832	United States 20,591	Japan 68,492	Japan 20,961
Republic of Korea 64,358	Japan 17,184	United States 56,778	United States 15,892

High growth locations (CAGR, 2018–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
India 21.8%	China 18.9%	China 17.1%	China 24.3%
Sweden 17.5%	India 15.8%	Italy 11.6%	Finland 17.8%
Belgium 13.4%	Italy 13.2%	Sweden 10%	Italy 15.6%

Highly specialized locations (Relative Specialization Index, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Germany 0.30	India 0.29	Germany 0.40	Israel 0.35
Republic of Korea 0.20	Sweden 0.24	Sweden 0.36	India 0.34
Austria 0.18	Germany 0.24	Israel 0.32	Germany 0.33

Top patent owners (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Toyota Motor 26,080	Toyota Motor 1,672	Toyota Motor 10,750	Denso 2,941
Panasonic Holdings 9,491	Hitachi 1,339	Denso 8,204	Toyota Motor 1,975
Honda Motor 8,737	Honda Motor 1,274	Robert Bosch 5,990	Volkswagen 1,828

Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Although China has rapidly emerged in the field of Land transportation technologies in recent years, the major patent holders are still from Japan, Germany and the United States (Figure 4.3). This is markedly different from the situation in Sea transportation, where 11 of the top 25 patent owners are Chinese academic institutions.

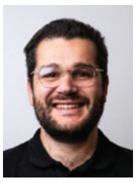
Among the top 10 patent owners in Land transportation, Japanese companies hold six positions (Toyota, Panasonic, Honda, Nissan, Denso and Hitachi), Germany has Bosch and Volkswagen, and the United States has General Motors and Ford. There are no universities or research institutions among the top 25. It is also worth noting that Tesla, a well-known EV manufacturer from the United States, has published only 347 patent families since 2000 and is not among the top 25.

Toyota holds the largest patent portfolio in Land transportation technologies, with over 37,000 patents, far surpassing second-ranked Denso. Across the four technology trends, as shown in Figure 4.4, Toyota ranks among the top patent owners for each technology trend, particularly so in Sustainable Propulsion, where it has published over 26,000 patent families – nearly three times that of Panasonic, which ranks second in Sustainable Propulsion. This is linked to Toyota's dual focus on electric and hydrogen fuel cell vehicles and its strategy of in-house battery production. In contrast, other car manufacturers are mostly focused on electric vehicles and typically rely on external battery suppliers.

In the field of Automation and Circularity technologies, Toyota, Hitachi, Honda and Bosch are the leading players. In Communication and Security technologies, Toyota leads with 10,750 patent families, followed by Denso with 8,204. For HMI technologies, Denso, Toyota and Volkswagen hold the most patent families.

Since 2018, CATL has led in patent growth rates in Sustainable Propulsion technologies, particularly in battery technology. Changan Automobile Group has achieved the highest patent growth rate in Automation and Circularity technologies since 2018. Kia has recorded the highest patent growth rate in Communication and Security technologies since 2018. The software and fabless company Nvidia, from the United States, has maintained a leading growth rate in HMI technologies since 2018.

EVs provide a promising future for Africa's rapid urbanization – Michael Maas, Zimi



Businesses and organizations are realizing they can self-generate power and utilize it instead of being reliant on fossil fuel. In South Africa, in particular, given frequent power outages, businesses have taken it upon themselves to approach the private sector to build energy resilience. This has led to a much faster adoption of renewables, primarily solar, both in private homes and commercial businesses. However, there has not been a comparable investment in energy storage, meaning there is an oversupply of solar-generated power. What we're seeing is that many businesses are evaluating electric vehicles (EVs) as a means of utilizing the excess energy instead of wasting it.

Zimi provides charging infrastructure – both the physical hardware and the related software and analytics platform required to manage the EVs that use the charging points. The chargers can be small enough to be wall-mounted to something like the size of your regular petrol pump; or much larger ones for charging trucks or fleets of vehicles, with a mix of personal, private chargers and shared public chargers.

That is today. In the future, battery energy densities will increase, vehicles ranges will increase and the charging capacities of chargers will also increase from kilowatts to megawatts. I foresee all this becoming a game-changer in how people start thinking about the energy part of the equation when they are using their vehicles.

We are also seeing rapid development of robotic charging. An autonomous vehicle could drive itself to a charger and a robot could charge it. This could also be really helpful when you have big, heavy cables for high-powered charging.

All these developments are really promising, but what keeps me up at night is energy availability. That is, making sure the infrastructure is managed properly, is reliable and that there is enough power to charge vehicles. Another thing that keeps me up is a bad actor; for example, an AI-based system implemented without thorough checks and balances in place, resulting in grid outages.

I also see EVs as an exciting future for South Africa. Africa is a rapidly growing, rapidly urbanizing continent. It has fast income growth and industrialization potential. Similar to mobile technology which leapfrogged developmental steps a few years ago, I see the same trend happening for EVs and energy in Africa.

Battery technology forms the core of Sustainable Propulsion, making up 78% of the total patent families in this category. The advantage of battery electric vehicles (BEVs) lies in their ability to significantly reduce greenhouse gas emissions, improve air quality and decrease fossil fuel dependence. However, further improvements in battery range and charging infrastructure are essential for broader adoption.

Sustainable carbon-based fuel technologies, like synthetic and biofuels, remain at the exploratory stage, comprising only 2% of the total patent families in Sustainable Propulsion.

Electric vehicles: a century-long struggle for better batteries – Tom Standage, The Economist

People have been trying to make electric vehicles mainstream for more than a century. The reason they failed was because the battery technology was not there. The batteries that were available were big and heavy. And even if electric cars had taken off a century ago, they would still have been charged using coal-fired power stations. So, we'd still have had an emissions problem.

It's not just the improvement in battery technology that makes electric vehicles a better option today – it's also the fact that we can charge them using electricity from renewable sources.

Unlike other technology trends, innovation activity in Automation and Circularity has not slowed since 2020; on the contrary, patent activity in recycling has accelerated, with a CAGR of 16.7% from 2018 to 2023. Smart production is the core area within Automation and Circularity technologies, covering industrial robots, smart factories, and predictive maintenance. This is the main research focus, representing approximately 84% of the total patent families in Automation and Circularity.

In the field of Communication and Security, navigation includes technologies such as GPS, lidar, and vehicle vision, which support autonomous driving and ADAS (advanced driver-assistance system), and hold the largest number of patents, making up approximately 73% of the total patents in this field.

From people-driven to autonomous: the shift towards constant mobility – Nikolas Badminton, Futurist

As we move away from the internal combustion engine and toward electric vehicles, I see a whole new ecosystem of "always on, always traveling" autonomous vehicles.

So you go from a people-driven world, in which people need to eat or sleep, to a world that is constantly on 24/7, 365 days a year.

Touch displays and data gloves have long been the HMI subgroup with the most patent activity, though their numbers began to decline after reaching a peak of over 2,600 patents in 2019. Recent patent activity shows a shift in research focus away from touch displays and data gloves and toward further developments in more immersive VR and AR, XR, metaverse and face/ facial recognition.

Within the four technology trends, Germany has the highest Relative Specialization Index (RSI) in Sustainable Propulsion and Communication and Security, while India holds the highest RSI in Automation and Circularity, and Israel leads in RSI for HMI. In terms of patent growth rates, in addition to the high growth rates of China and India, Italy also shows significant growth across all four technology trends.

Interdisciplinary collaboration and technological innovations: transforming railways for the future – Grigore Havârneanu, International Union of Railways (UIC)

In the UIC Security Department we deal mainly with the threats to the system and, when we talk about the evolution of transportation trends, we try to think more of how the threats will evolve. With increasing digitalization and interconnectivity, threats are increasing: from petty crimes and daily incivilities to more serious forms of attack. There is now a lot of work going on in this area.

Apart from the technical side of things, there is also the human factor. We strongly believe that the human factor can be the weakest point in the security chain. But it could also be the strongest point or the biggest asset, if properly informed and trained. It is a sensitive area but work around it is growing exponentially. Safety and security have now become part of the design process, so we cannot imagine developing a new system without including security from the outset.

If a station is designed in 2025, it will include different security features: AI-based intelligent cameras with automated alerts, ballistic protective materials, open spaces etc. In the future, I think we are heading toward a world in which you are able to do security more effectively and still in a seamless way.

However, threats are also evolving much faster today and becoming less predictable. We rarely see the types of attack today unlike the ones 20 years ago. Not only are there physical threats, but also digital attacks or a combination of the two.

There is also more work being undertaken on identifying and defining how to make rail transportation more inclusive and on identifying who is vulnerable. Inclusivity is equally critical. UIC is advancing initiatives to accommodate vulnerable passengers, including persons with disabilities, women, children, and those unfamiliar with local transport systems. By prioritizing accessibility and personalization, UIC aims to make rail transport truly universal. In our past research we realized that vulnerability affects not only traditional groups like women and children, but that anyone can become vulnerable, depending upon the situation. For example, you can be vulnerable, when you are a tourist in a city new to you and don't speak the local language and cannot understand public announcements made in a station during an incident.

In the future, I see humans as the key factor that will transform rail transport. Today, cross-sector cooperation exists but is still rather limited. The transformation of the rail sector depends on interdisciplinary collaboration. UIC fosters partnerships between engineers, urban planners, digital innovators, and social scientists to address complex challenges holistically. By bringing together diverse expertise, UIC supports the development of a global rail system that is not only innovative but also balanced, inclusive, and sustainable.

Despite the ever-increasing amount of patenting activity being undertaken globally in Land transportation, it is important to also remember that effective management of trade secrets is critical. In the fast-evolving electric vehicle (EV) industry, for example, managing trade secrets effectively is essential for staying competitive and driving innovation. Although patents and trademarks are common in IP strategies, trade secrets are gaining importance because they allow companies to protect technologies like battery design and autonomous driving algorithms without public disclosure. This approach helps firms like Tesla, Rivian and Volkswagen maintain a competitive edge by keeping advancements confidential and accelerating market entry.[3] Additionally, trade secrets are cost-effective, because they avoid the expense associated with patents, making them an efficient way for companies to protect proprietary materials and processes.

A more detailed deep-dive analysis of patenting in Land transportation can be found in the technical annex "Future of Transportation on Land."

Sea transportation

Sea transportation – also known as maritime transport – is a crucial component of global trade and travel, responsible for over 80% of the world's goods trade. It involves the movement of passengers and cargo across bodies of water using a variety of vessels such as cargo ships, tankers, ferries, and cruise liners. Although air travel has reduced the significance of sea travel for passengers, it remains a preferred mode for shorter distances and leisurely cruises, contributing to coastal and marine tourism.

The global economy relies heavily on Sea transport, with total seaborne trade expected to grow by around 35% until 2050, driven by a growing and more affluent global population. However, the shift toward a more circular economy will impact sea trade, leading to a decline in the transport of coal and oil. Container ships and gas carriers are expected to show strong growth, while the highest growth rates are forecast for specialized vessels serving the offshore wind industry.

The two significant megatrends, Sustainability and Digitalization, will undoubtedly shape the future of the maritime industry. Shipping is the most energy-efficient way to move large volumes of cargo over long distances, but its sheer size means it has a significant environmental impact. International shipping contributes around 3% of global greenhouse gas emissions – similar to aviation – but has a higher share of global sulfur and particulate matter emissions.

The promise of unmanned shipping – Robert Garbett, Drone Major Group

Although the maritime industry is slow to catch up and to evolve, I see huge potential in unmanned shipping; in particular, maritime autonomous surface shipping for cargo. With no pilot and only a skeleton crew necessary to make sure all systems are working correctly, the cost savings will be huge. It will be slow to take off, because the cost of replacing a working oil tanker or cargo vessel is huge, and there is already a lot of them currently in service.

To achieve a more sustainable shipping industry, the International Maritime Organization (IMO) has revised its emissions reduction targets so that they align with the Paris Agreement's ambitions, aiming for a 15% reduction in emissions by 2030 and net-zero shipping by 2050. Digitalization also holds promise for shipping, with the potential to optimize ship movements, reduce fuel consumption and improve connectivity between land-based and maritime logistics networks.

3 See, for example, Proskauer (2024), The critical role of trade secrets in the booming EV industry, available at: www.proskauer.com/blog/the-critical-role-of-trade-secrets-in-the-booming-ev-industry; and WIPR (2024), Tesla's $1bn secrets suit exposes potholes for electric vehicle makers, available at: www.worldipreview.com/teslas-dollar1bn-secrets-suit-exposes-potholes-for-ev-makers.

Maritime decarbonization is a complex challenge but one with a promising future – Carlos Ruiz, International Renewable Energy Agency (IRENA)

The maritime sector is a vital component of the global economy, responsible for transporting over 80% of global trade by volume. However, despite being one of the least carbon-intensive transport modes, the sector still contributes significantly to global emissions because of its sheer volume of activity. The urgent need to decarbonize this sector cannot be overstated, because the vessels deployed within the next few years will largely shape what will be the fleet and fuel mix two-to-three decades from now. And the maritime sector will undoubtedly play a role in enabling the decarbonization of other transport and industrial sectors, transporting the fuels and feedstocks of the future.

Full decarbonization will require the maritime sector to move away from its fossil fuel reliance. To achieve this, a combination of different solutions or pathways will need to be employed, all of which have innovation as a common denominator. The first pathway is increased efficiency, in the form of technology and operational improvements. Efficiency improvements are the best way to deliver emission reductions in the short-term and keep a timely decarbonization within reach through reducing the energy intensity of the sector.

The second pathway is direct electrification, which is particularly relevant for decarbonizing short and inland routes, as well as operations at port. The provision of onshore power in ports and harbors can deliver substantial emission reductions, given that some shipping segments spend considerable time in port, usually burning fossil fuels. Beyond this, if the meteoric rate of improvement in battery technologies continues, the electrification of longer shipping routes could become a reality, at least partially through battery-hybrid ships.

The third pathway is the use of sustainable biofuels, such as renewable diesel, bio- LNG and bio-methanol. Biofuels are a key decarbonization option for the sector, not only as a fuel but potentially as a source of biogenic carbon for e-fuel production.

Biofuels boast high technological readiness, allowing them to be immediately harnessed as blends or drop-in fuels, requiring little to no change in terms of operation and infrastructure, and offering the potential for emission reductions in the short-to-medium term. However, the rapid scale-up of sustainable biofuels will require strict controls along the entire supply chain, robust standards and certification mechanisms, and substantial policy intervention to guarantee sustainability.

The fourth pathway – relevant for the medium-to-long term – is the use of e-fuels made from green hydrogen, such as e-methanol and e-ammonia. E-fuels can be produced using renewable power and have the advantage that, on paper, they could satisfy virtually unlimited demand. However, they also come with limitations, such as the potential of e-methanol being limited by the need to source carbon sustainably (from the atmosphere or from biogenic sources) to synthesize it, and the use of ammonia as a fuel presenting operational and safety concerns.

The last pathway could be the use of carbon capture technologies. The maritime industry is increasingly looking at the possibility of implementing onboard carbon capture systems. This could prevent emissions from biofuels or e-fuels reaching the atmosphere and solve the sustainable carbon sourcing issue. However, there are a number of challenges that would need to be solved before this becomes a reality, starting with the logistical aspects of handling captured carbon from potentially thousands of vessels docked at ports.

In addition, digital technologies will necessarily play a supporting role in the success of all these pathways. Digitalization will be critical for tracking the progress of the transition and the impacts of mitigation measures. The data collected through the digitalization of ships and smart ports will be crucial to unlocking efficiency improvements in technologies, through data-driven improved designs, and in operations, through optimized or even automatized operations.

Ultimately, the decarbonization of the maritime sector is a complex challenge, but one that I believe is achievable. A combination of solutions, including increased efficiency and the adoption of renewable-based technologies, such as electrification and renewable fuel alternatives, supported by digitalization, will be needed. We have all the pieces of the puzzle laid out before us. Now the task is to fit them all together with the help of ambitious policies and standards coupled with decisive action.

Transitioning to more sustainable forms of propulsion is key to reconciling continued growth with decarbonization targets. Technological breakthroughs are advancing low and zero-emission solutions, including more sustainable carbon-based fuels, hydrogen, methanol, ammonia, electric propulsion, and optimizing energy consumption through efficient ship design. However, scaling up production and ensuring the cost-effectiveness of carbon-neutral fuels remains a challenge.

Regulation has a crucial role to play in the development of greener ships. Clear regulations are needed to drive investment in sustainable fuels and the required infrastructure, bringing down costs and making them more viable for shipowners. Communication and Security technologies are making ships smarter and safer, with key research areas including navigation, device-to-device communication, low- latency communications, cloud platforms, and cybersecurity. Piracy and terror attacks remain a threat in international shipping, with global piracy and armed robbery incidents having increased by 4% in 2023 compared to 2022.

Geopolitics, human resources, environmental regulations and digitalization will be key drivers shaping our priorities – Thomas Ting, Maritime and Port Authority of Singapore

The sea transport industry is essential to global trade and supply chains, with more than 80% of cargo transported by sea. As one of the busiest hub ports in the world, the Port of Singapore is connected to some 600 ports around the globe. The major drivers shaping our priorities include global shipping trends, human capital and resources, environmental regulations, technology and digitalization.

Geopolitics and strained supply chains have had and will continue to have a major impact on global shipping, and the competitiveness of hub ports will largely be determined by their ability to efficiently and reliably handle the needs of mega vessels and shipping alliances. The pace at which hub ports digitalize, automate, decarbonize, and equip their workforce to be future-ready will also play a part.

At the same time, environmental regulations by governments will be a key enabler to accelerate global decarbonization efforts. The International Maritime Organization has set a target for international shipping to achieve net-zero greenhouse gas emissions by or around 2050[4], and the mid-term measures to reduce GHG emissions from shipping are scheduled to be approved at the IMO's 83rd Marine Environment Protect Committee in April 2025.

The maritime industry is also undergoing a digital revolution, with Industry 4.0 technologies transforming and disrupting many industries. Digital solutions and cybersecurity are key enablers for the maritime industry, with increasing use being made of big data, artificial intelligence, remote technologies, robotics and Internet-of-Things to improve supply chain efficiency and reduce energy consumption, transaction cost and time.

In response to these challenges and opportunities, the Maritime and Port Authority of Singapore (MPA) has taken key steps to remain efficient and future-ready. These include developing the Next Generation Port at Tuas, which will have a handling capacity of 65 million twenty-foot equivalent units (TEUs) when fully operational in the 2040s. The MPA is also investing in digitalization and cybersecurity, and has set up a Maritime Cybersecurity Assurance and Operations Centre (MCAOC) to provide real-time security monitoring and

4 The 80th session of the IMO MEPC meeting concluded in July (2023), with all member states agreeing to reduce GHG emissions from international shipping as soon as possible and to reach net-zero GHG emissions by or around 2050.

disseminate information to mitigate cyber threats, as well as the DigitalPORT@SG platform to digitalize port services and regulatory processes.

The MPA is also collaborating with international partners to pursue decarbonization efforts, and aims to provide zero/low carbon marine fuel and bunkering infrastructure to accelerate the adoption of global standards and solutions. Domestically, the port and harbor craft sector will need to achieve net-zero emissions by 2050 to support the new national climate target.

A focus on innovation and R&D are remain key priorities, with the MPA supporting numerous R&D projects and training research scientists and engineers. The MPA, together with NUS Enterprise, launched the PIER71 initiative in 2018 to attract global startups and entrepreneurs into the maritime industry and support over 140 marinetech startups.

The sea transport industry, particularly in Singapore, is going through a phase of significant evolution and change. The industry can expect new areas for development and investment, along with the creation of new jobs and future skills with the digital and green transition. These developments will create opportunities to transform how we work and function, to ensure we remain efficient and build the maritime workforce of the future.

A snapshot of the patent landscape in Sea transportation, highlighting historical patenting activity, technology trends, key locations and top filers

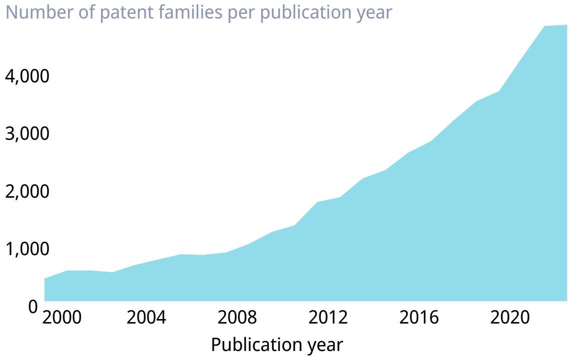
Figure 4.5 Exploring the patent landscape in Sea transportation

46,649 Sea transportation

Number of patent families in Sea transportation, 2000–2023

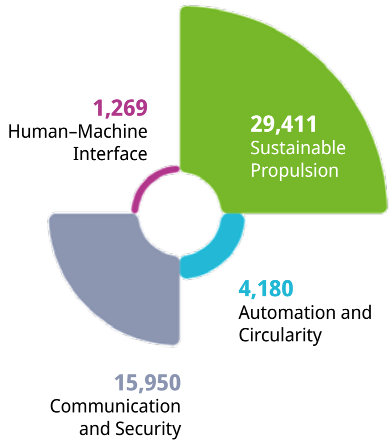
Patent publication trend

Number of patent families per publication year

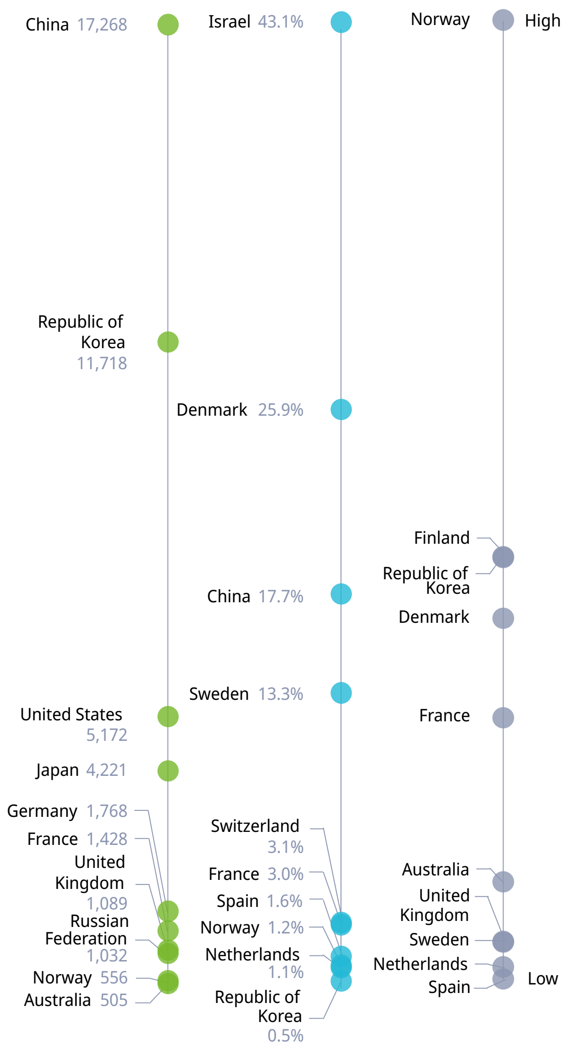


Technology trends in Sea transportation

Number of patent families, 2000–2023

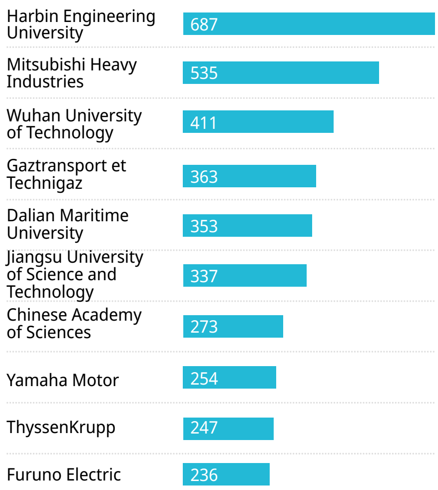


Top inventor locations



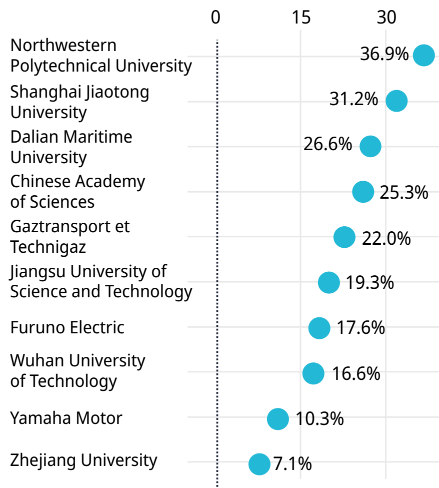
Top patent owners

Number of patent families, 2000–2023



High growth patent owners

CAGR, 2018–2023



Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Automation and Circularity technologies will boost productivity and enable more energy-efficient ships, with key research themes including efficient material use, smart production and robotics technology, and recycling.

HMI technologies are emerging as useful tools to improve the way we interact with ships. However, all HMI technologies are still in the early stages of development and adoption in shipping. Research areas include extended reality technologies, speech recognition technology, facial recognition, and touch displays.

Are sailing boats making a comeback with wind-powered cargo delivery? – Nikolas Badminton, Futurist

The biggest revolution happening in transportation is around energy.

There is a cargo ship that uses wind power to sail across oceans, like the big sailing ships of yesteryear. And that revolution is looking backward. This wind-powered ship just made its first delivery across the Atlantic.[5]

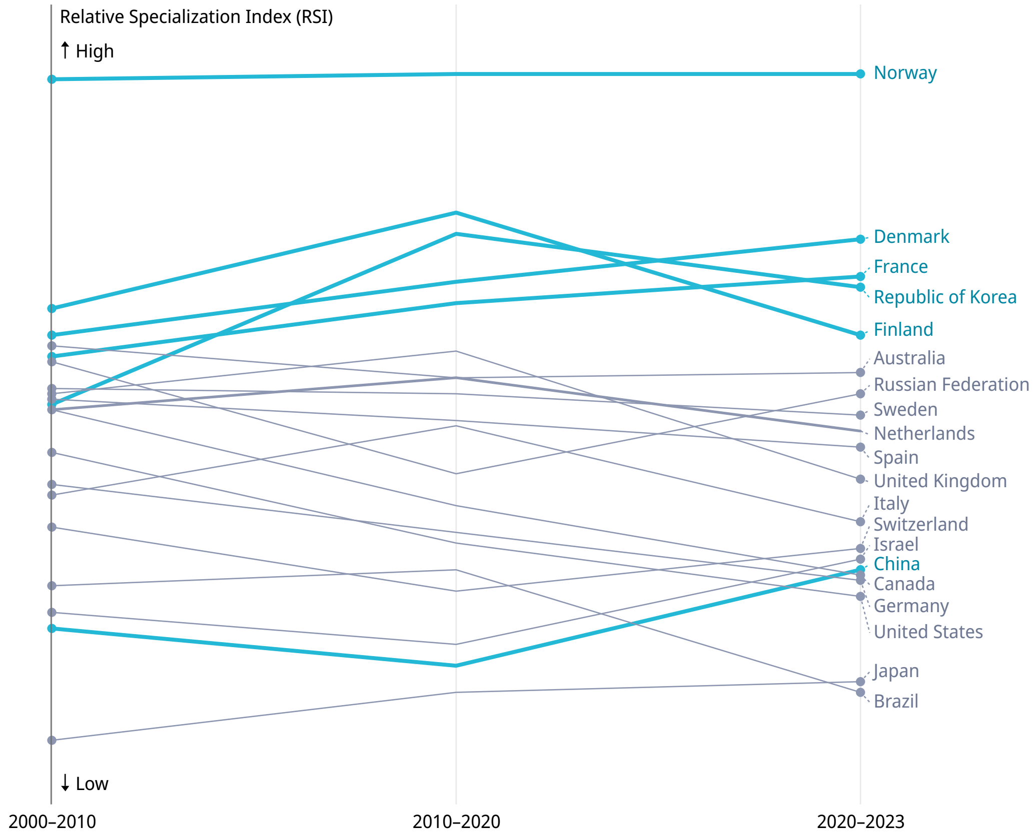
In terms of the levels of patenting activity, the maritime sector is the smallest of the four principal transport modalities studied, with almost 47,000 inventions in Sea transport in total since 2000 (Figure 4.5). Over 70% of all Sea transport patents come from Asia (Europe 14% and North America 11%), led by China (36%), the Republic of Korea (25%) and Japan (9%). China's growth has been on an upward trajectory since 2016, whereas the increase from the Republic of Korea started earlier in 2010 but since 2012 annual filings from Korean inventors have remained relatively stable. Denmark is the most dynamic European nation and there are also signs of recent growth in Sweden, although absolute patent numbers remain relatively small.

The Relative Specialization Index (RSI) for Sea transport technologies illustrates the important role that the maritime industry plays in Norway and that it has stood the test of time (Figure 4.6). The patenting of shipping technologies is also very important in Denmark, France, the Republic of Korea, and Finland, with ever-increasing levels of relative specialization seen in both Denmark and France. Interestingly, although China is a clear leader in terms of its absolute number of Sea patents, the RSI measure shows that China is less specialized than you would expect given the propensity to patent in China in general and the total level of patenting activity across all technologies seen in China.

5 See, Fast Company (2024), The world's largest wind-powered cargo ship just made its first delivery across the Atlantic. Available at: www.fastcompany.com/91185144/the-worlds-largest-wind-powered-cargo-ship-just-made-its-first-delivery-across-the-atlantic.

Norway has long been the leading specialist location in Sea transportation, and remains a clear leader despite recent increases seen in Denmark and France

Figure 4.6 Changes in Relative Specialization Index (RSI) across inventor countries in Sea transportation, 2000–2023

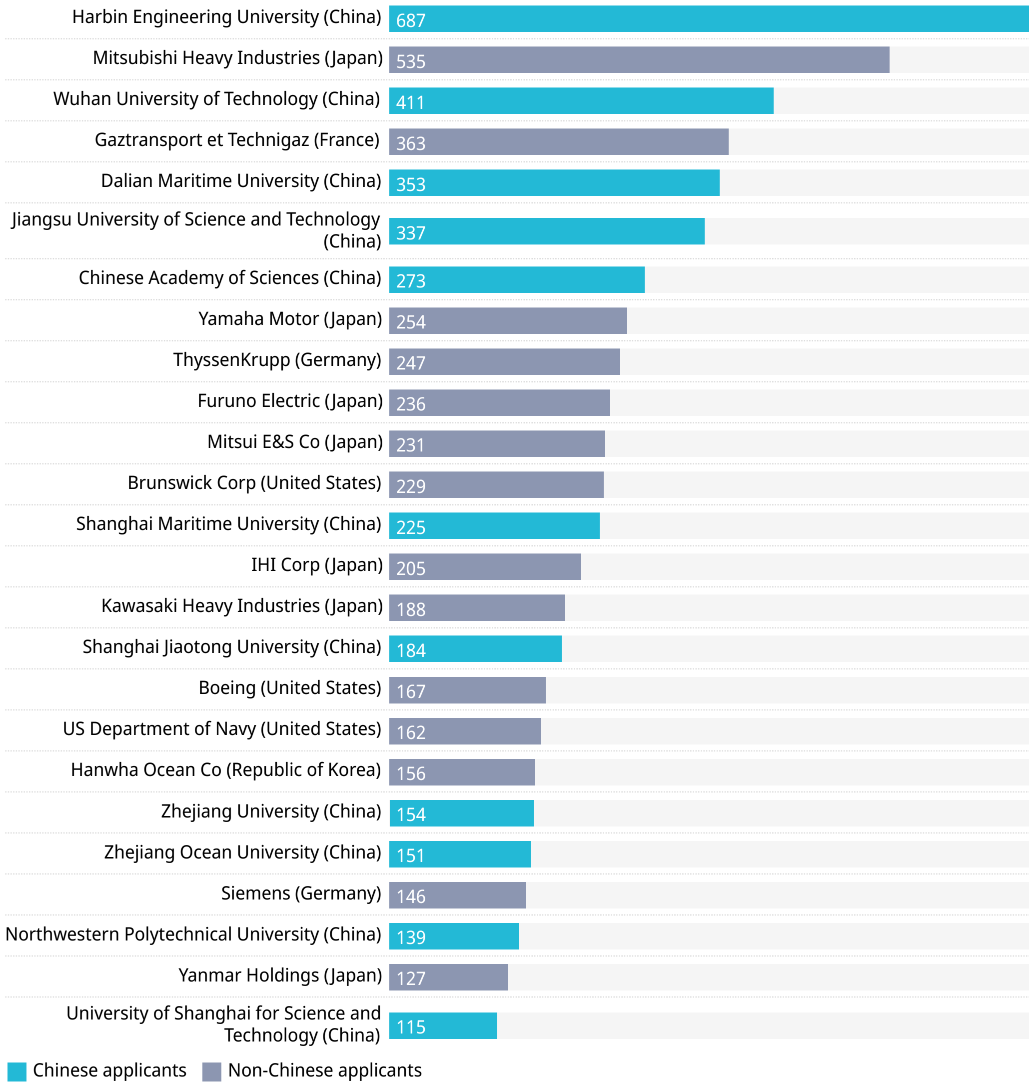


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Given the absolute levels of patenting activity from China it is not surprising to see that 11 of the top 25 Sea transport patent owners are Chinese (Figure 4.7). What is interesting, however, is that all 11 of these Chinese patent owners in the top 25 Sea transport patent owners are academic institutions, and that the other 14 top patent owners (seven from Japan, three from the United States, two from Germany and one from each of France and the Republic of Korea) are all non-academic players.

In contrast to the rest of the world, all of the top patent owners in Sea transportation from China come from academia

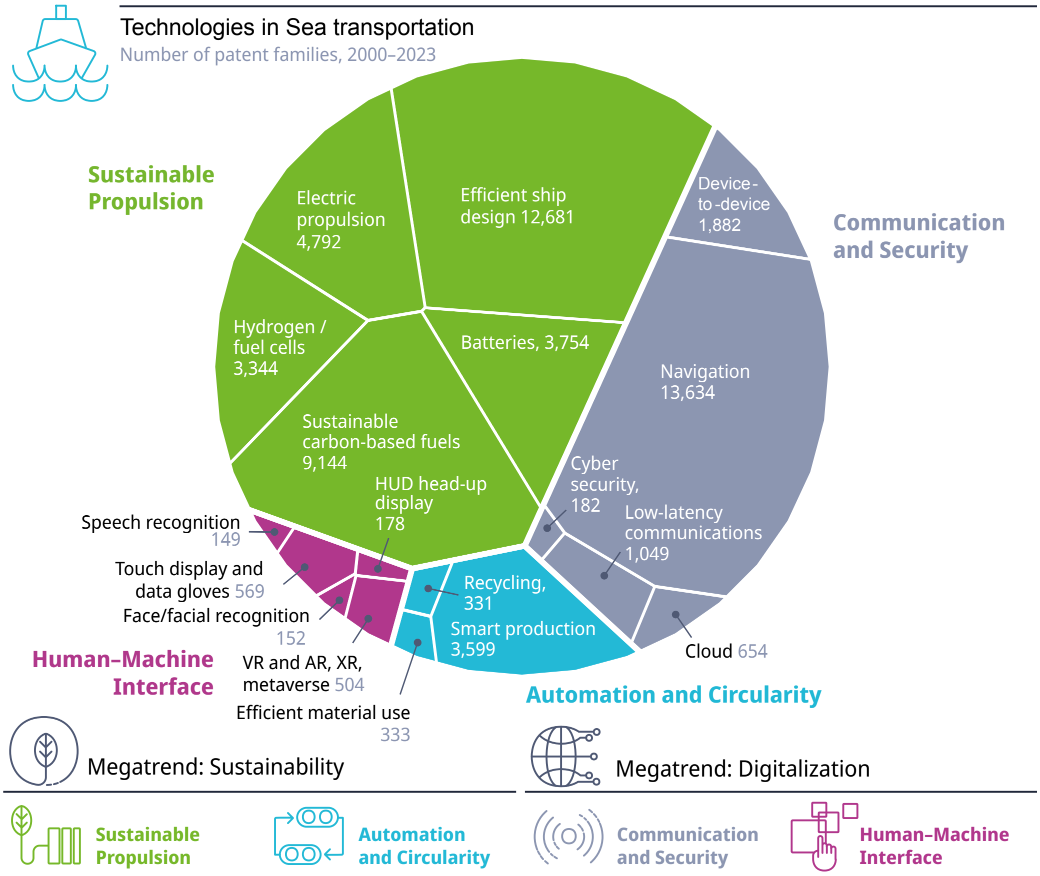
Figure 4.7 Top 25 patent owners in Sea transportation, based on the number of patent families, 2000–2023



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

A snapshot of the patent landscape in Sea transportation in each of the four technology trends, highlighting key locations and top filers

Figure 4.8 Exploring the patent landscape in Sea transportation in the four technology trends



Top inventor locations (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
China 9,169	China 2,313	China 7,377	United States 316
Republic of Korea 8,867	Republic of Korea 876	Republic of Korea 2,448	China 316
United States 3,035	United States 402	United States 2,077	Republic of Korea 263

High growth locations (CAGR, 2018-2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Austria 51.6%	Canada 14.9%	Israel 58.5%	Germany 20.1%
Denmark 32%	China 10.8%	Denmark 24.6%	China 12.3%
Sweden 24.6%	Germany 3.1%	China 17.4%	Republic of Korea −3.6%

Highly specialized locations (Relative Specialization Index, 2000 –2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Norway 0.87	Norway 0.83	Norway 0.80	Finland 0.75
Republic of Korea 0.55	Republic of Korea 0.41	New Zealand 0.59	Israel 0.51
Finland 0.49	China 0.11	Finland 0.53	United Kingdom 0.47

Top patent owners (Number of patent families, 2000 –2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Mitsubishi Heavy Industries 401	Harbin Engineering University 118	Harbin Engineering University 324	Furuno Electric 58
Gaztransport et Technigaz SA 362	Chinese Academy of Sciences 71	Furuno Electric 229	Brunswick Corp 22
Harbin Engineering University 325	Dalian Maritime University 62	Wuhan University of Technology 208	Teledyne Technologies 22

Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

At the level of the four technology trends, as shown in Figure 4.8, most research activity in maritime transport is focused on Sustainable Propulsion/Efficient Ship Design technologies. Between 2000 and 2023, the number of published patent families increased annually from less than 300 to more than 2,800. In this field, the most important area in terms of patent families is efficient ship design. This includes research activities focused on optimizing hull shape so as to minimize drag, designing efficient propellers or introducing air bubbles under the hull. China is the leader in efficient ship design, batteries and electric propulsion, and the Republic of Korea has published the most patent families in hydrogen/fuel cell research and sustainable fuels. Another important research area is sustainable carbon-based fuels. The vast majority of patents in this area relate to liquified natural gas (LNG) fuels for ships.

The rise of electric hydrofoil boats – Tom Standage, The Economist

Electric boats are something to watch out for in the future. There is a company (Candela) that makes them now. They are hydrofoil boats and they're incredibly fast and incredibly energy efficient, because they basically lift the whole boat out of the water. You could imagine this being an amazing transformative technology in places where waterways are the easiest way to get around.

Communication and Security is another key research area, with the annual number of inventions published increasing from less than 100 in 2000 to over 1,800 in 2023. China and the Republic of Korea lead the way across all four technology trends, but the United States has a clear strength in HMI technologies and matches the Asian leaders in this area. Most patenting activity takes place in navigation technologies such as lidar, radar, sonar or GPS, with device-to-device communication the second most important area of patenting.

For almost all of the top inventor locations, Sustainable Propulsion/Efficient Ship Design is the main area of patenting, followed by Communication and Security technologies. The only exception is Israel where patenting activity in Communication and Security technologies outweighs activity in the field of Sustainable Propulsion/Efficient Ship Design.

Smart logistics and AI will play a key role in cargo transportation – Seyedeh Fatemeh Moghimi, Sadid Bar International Shipping and Transportation Ltd

Profound changes in technology will lead to fundamental changes in the transportation industry. These changes can be in different areas. A fundamental revision in transport regulation and a fundamental redefinition of the fields of safety, the use of clean fuel, and a drastic reduction of the carbon footprint in the transport industry will be different aspects of the change to come in the future of transport.

Although in the Middle East various aspects of transportation have been associated with technological changes, a change in transportation regulation has resulted in the area of transportation management having been given more attention than other aspects. A financial and economic crisis in the region has raised many barriers to the introduction of modern technologies, as well as fleet modernization. In addition to this issue, government subsidies and very cheap fuel prices have caused transportation efficiency to be low, and there is no clear pathway toward changing this situation and increasing efficiency.

The issue of smart logistics has been given serious attention by the private sector and goods producers. In recent years, the passenger transportation sector has undergone fundamental changes, with the creation of transport management platforms; and, currently, major platforms have taken over the vast bulk of passenger transportation.

Similarly, despite the existence of many obstacles in the field of regulation and technology, progress has been made within the cargo transportation sector. Although the initial process of change is at the early stages, the future will belong to smart logistics. And it seems that the resistance of the traditional sector of the industry to the wave of changes taking place is fragile; and in the future, most of the cargo transportation industry in the region will use modern technologies. The use of artificial intelligence is on the path of change and this will lead to an increase in the efficiency of cargo transportation in the region. Considering the increase in fuel consumption within the region's transportation sector, coupled with an increase in the cost of fuel subsidies for governments in the Middle East, governments are expected to play a role as the main regulator of the transportation industry in the region supporting these changes.

This will be the basis for future changes. And, looking ahead, we could see more changes in various sectors such as the development of self-driving cars, alternative and clean fuels, as well as new regulations regarding the use of blockchain technology in the field of transportation.

I believe there has been a recent step change in transportation in the Middle East and we can be optimistic about the fundamental changes in the future of transportation in region. From my field observations, I foresee the emergence of smart logistics companies and the use of AI in cargo transportation platforms playing a role as the engine driving change in other areas of transportation.

In the maritime sector, lower levels of patenting activity are seen in Automation and Circularity and HMI. Automation and Circularity technologies for Sea transport include the areas of smart production, efficient material use and recycling. Smart production (including robotics) is the key area of patenting within Automation and Circularity. HMI technologies are at an early stage of development and adoption within the shipping sector, which is also reflected in the limited amount of patenting activity to date.

A more detailed deep-dive analysis of patenting in Sea transportation can be found in the technical annex "Future of Transportation on the Sea."

Air transportation

Air transportation is a crucial mode of travel and commerce, involving the movement of people, goods, and animals through the atmosphere using aircraft such as airplanes and helicopters. It is indispensable for the overall transportation system, because of its speed and the ability to cover long distances quickly, connecting remote regions and major economic hubs. Air transport plays a significant role in global trade and passenger mobility, influencing economic development and international relations. However, its share of CO_2 emissions is significant, accounting for 2% of global CO_2 emissions in 2022, and expected to increase under current policies. Efforts to decarbonize the air transport sector are essential for reducing emissions and achieving sustainable mobility.

Sustainability and Digitalization are megatrends transforming the future of air transport. Sustainable Propulsion technologies such as efficient aircraft turbines, sustainable aviation fuels, battery-based electric and/or hybrid aircraft, and hydrogen-powered aircraft are being developed to reduce emissions and improve environmental sustainability. A resurgence of modern airships[6] could also be the future of sustainable air travel – airships are energy-efficient and cost-effective, floating without using energy and consuming less energy at slower speeds, with a design that supports zero-emission technology. With lower costs and environmental benefits, airships could transform transportation, if society is prepared to accept a slower travel time akin to that of trains in order to have a more sustainable future.

Automation and Circularity technologies are promoting efficient material use, smart production, and enhanced recycling practices. Communication and Security technologies, including navigation technologies, device-to-device technology, cloud computing and low-latency internet, are revolutionizing air transportation by improving operational efficiency, safety and customer experience. Advanced Human– Machine Interfaces, such as extended reality technologies, speech recognition technology, facial recognition technology, touch displays,

6 See, for example, www.hybridairvehicles.com.

and head-up displays, are making interactions more intuitive, secure, and responsive, thereby improving operational efficiency and user experience.

The International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO) are both committed to reducing aviation emissions by up to 50% by 2050 through ambitious policies and the transition to sustainable aviation fuels and efficiency technologies. Digitalization is driving significant advancements in efficiency, safety and customer experience, with operational cost reductions of up to 20% reported.

Global collaboration drives the future of air transport – Juan Carlos Salazar, International Civil Aviation Organization (ICAO)

When States delegates convened in Chicago in 1944 to conceive the Convention on International Civil Aviation, which remains the legal foundation for the vast air transportation industry, they could hardly have imagined how thoroughly air transport would become embedded in global society. Their aspirational preamble about aviation fostering prosperity and "friendship and understanding among nations" now seems prescient: air transport has become a critical, unique, and irreplaceable catalyst for development and peace worldwide.

Meanwhile, the eight decades of evolution since demonstrate the profound relationship between air transport and technological advancement. It is a dynamic that is accelerating at an unprecedented pace, becoming exponentially evermore sophisticated, and important. Since its creation by the Convention, the International Civil Aviation Organization’s (ICAO) role has therefore also evolved in tandem.

Aviation is a technology-intensive industry that demands a careful balance between innovation and the status quo. Jeopardizing the highest safety standards that have characterized civil aviation's development would threaten the future of aviation itself. As a result, ICAO is now helping its Member States elaborate regulatory frameworks that actually encourage even the most disruptive innovations while safeguarding lives and livelihoods.

This is happening today. The convergence of artificial intelligence (AI), automation, and advanced materials, for example, is reshaping the industry's fundamentals. AI and machine learning are already operational necessities, deployed in everything from predictive maintenance to flight path optimization. Advanced analytics now power everything from passenger flow management to aircraft component lifecycle prediction, while automated systems increasingly handle complex operational decisions that once required human intervention. Weather analysis has become granular enough to trim both fuel costs and the effects of turbulence.

These are just some illustrations of how technologies are fundamentally altering how aviation works, and we are just at the dawn of this new era. At the macro level, technological advancement will serve as a key enabler for achieving greater sustainability, efficiency, and economic viability across the aviation ecosystem.

Modern aircraft surveillance illustrates this complexity perfectly: space-based Automatic Dependent Surveillance-Broadcast/Contract (ADS-B/C) systems now complement traditional radar and airborne surveillance, demonstrating how space, air, and ground technologies can work in synergy despite their distinct regulatory frameworks. This integration hints at a future where transport modes become increasingly interconnected, demanding innovative applications of technology toward common objectives.

Indeed, the COVID-19 pandemic, for all its devastation, provided almost a “reset” moment for aviation that triggered an accelerated digital transformation. At ICAO, digitalization was implemented to assure the operation of tasks as widely varied as the new Public Health Corridors created to the environmental certification that remains at the heart of our response to the climate crisis. This catalyzed wider innovations, from digital identity verification to enhanced cargo tracking systems.

Digitalization will also be key to assuring the success of the most visible revolution in air transport, which is occurring in urban airspace. Electric Vertical Takeoff and Landing (eVTOL) vehicles are moving from concept to reality, bringing with them sophisticated autonomous systems and dedicated air corridors. These developments incorporate fuel-flexible propulsion systems and embrace the principles of Urban Air Mobility (UAM) initiatives. These systems incorporate advanced sensing technologies, real-time communication networks, and artificial intelligence to maintain separation between aircraft while optimizing airspace usage.

Of course, medium and long-haul flights are transforming too. New technologies addressing fuel efficiency and sonic boom are expected to facilitate a sustainable reintroduction of supersonic flight, and we also see innovative propulsion systems and aerodynamic designs holding the promise of hypersonic capabilities revolutionizing long-distance travel.

New business models are emerging to capitalize on this connectivity. Success however will require unprecedented collaboration between established players, startups, regulators, and researchers, and this is where ICAO plays a unique and powerful role as a platform for collaboration. These advances promise to unlock new industries and high-skilled employment opportunities across both developed and developing States, helping to address global economic imbalances through expanded aviation capabilities and expertise.

All of this is taking place against the backdrop of the sustainability imperative, encompassing its environmental and socio-economic dimensions, which presents aviation's greatest challenge. Air connectivity underpins all modern societies, but it is a particularly vital humanitarian and economic lifeline for least developed countries (LDCs), small island developing States (SIDS), and landlocked developing countries (LLDCs). The fact that growth in air connectivity is forecast to take place precisely where it is needed most points to the critical importance of safeguarding this expansion by ensuring aviation responds effectively to the climate crisis.

States working through ICAO have agreed to a net-zero carbon emissions goal by 2050, supported by a Global Framework for Sustainable Aviation Fuels, Lower Carbon Aviation Fuels, and other cleaner energy solutions.[7] Member States are striving to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5% by 2030, compared to zero cleaner energy use.[8] The industry is pursuing this transformation through multiple complementary paths - hybrid-electric propulsion, hydrogen power, fuel-flexible systems, and operational efficiencies - ensuring no viable solution is left unexplored.

Technologies are being developed alongside advanced materials and manufacturing processes to reduce aircraft weight and improve aerodynamic performance. Patents provide the necessary framework for securing these investments, while international cooperation ensures that technological advances benefit the entire aviation community. Yet success requires political commitment, infrastructure investment, and financial incentives that align commercial interests with environmental goals. Joining these goals and the leaders who can back them is another current focus of ICAO’s work.

To navigate this complex future landscape, ICAO is also institutionalizing foresight analysis and horizon scanning disciplines. These systematic approaches enable better situational awareness of future scenarios and facilitate participatory analysis for decision-making about innovations. The organization will further employ advanced modeling techniques, scenario planning tools, and collaborative frameworks to anticipate and prepare for emerging challenges. These methodologies incorporate input from diverse stakeholders, ensuring that future developments consider technical, operational, and regulatory perspectives.

International civil aviation's strength lies in its operation as a unified global system, where each State's participation strengthens the whole. Through ICAO's Strategic Plan 2026-2050, the international aviation community has crafted a vision that balances ambition with pragmatism,

7 ICAO (2022). States adopt net-zero 2050 global aspirational goal for international flight operations. Available at: www.icao.int/Newsroom/Pages/States-adopts-netzero-2050-aspirational-goal-for-international-flight-operations.aspx.
8 ICAO (2023). ICAO Special Environment Report on Aviation Cleaner Energy Transition. Available at: www.icao.int/environmental-protection/Documents/ICAO%20Special%20Environment%20Report%20on%20International%20Aviation%20Cleaner%20Energy%20Transition%20.pdf.

innovation with safety, and global progress with local needs.[9] Taken with the UN agency's "no country left behind" strategic goal which is building capacity worldwide, the plan's implementation will showcase how coordinated international action can transform visionary goals into operational reality.

The Air transportation sector is undergoing a transformative change driven by Sustainability and Digitalization, affecting both passenger and freight services. Global passenger kilometers are projected to nearly double between 2019 and 2050, primarily due to economic growth in emerging markets.[10] This expansion is paralleled by a surge in patenting activity, with annual Air transport-related patent families increasing from under 1,100 in 2000 to over 12,800 in 2023 – a CAGR of 11%. Patents in Automation and Circularity technologies, in particular, have grown rapidly, with a 16% CAGR since 2000.

This is summarized in Figure 4.9, which shows significant global innovation and a total of over 131,000 patent families in Air transportation between 2000 and 2023. China, the Republic of Korea, and Japan stand out for their high patent volumes and significant growth rates, although they exhibit a relatively low Relative Specialization Index (RSI), suggesting a broad approach to innovation at the country-level across various sectors. In contrast, France, the United States and Canada demonstrate a high degree of specialization in Air transportation technologies, as indicated by their higher RSI values, reflecting a concentrated focus on advancing specific innovations in aviation.

Leading aviation companies such as RTX, General Electric, Safran, and Boeing dominate the patent filings, underscoring the competitive nature of the industry. The Aero Engine Corporation of China leads in recent growth with an impressive compound annual growth rate (CAGR) of 81.1%. Notably, Mitsubishi Electric in Japan emerges as the only non-Chinese entity among the fastest-growing patent owners, highlighting its strategic emphasis on Air transportation research and innovation. This diverse landscape underscores the dynamic interplay of high-volume patenting and strategic specialization across different regions, driven by both established aviation multinationals and emerging players.

Innovative aerial services can transform urban mobility and city operations – Vassilis Agouridas, IAS expert

Innovative aerial services (IAS) refers to "new urban/metropolitan/regional traffic," whether purely for mobility (of people and goods) or for city (metropolitan and regional) public services and operations (for example, security, law enforcement, surveillance of critical infrastructure, environmental monitoring), and has the potential to improve city operations and services.

Urban air mobility (UAM) is a key component of IAS, utilizing drones and electric vertical take-off and landing (eVTOL) vehicles to transform urban transport.

Advancements in autonomous navigation, battery technology, hydrogen energy technologies, and data-driven flight and fleet management are driving the growth of IAS. However, the integration of IAS into existing transportation systems remains a challenge. To address this, a shared digital infrastructure enabling secure and interoperable data exchange is needed. Urban planners and policymakers are beginning to include urban air mobility in sustainable urban mobility plans, recognizing the need for an integrated transport network connecting air and ground transportation.

The integration of urban air mobility into existing intelligent transport systems and mobility-as-a-service (MaaS) systems is essential for coordinating traffic flows, managing real-time navigation data, and ensuring safety across different mobility modes. This requires a

9 ICAO Strategic Plan 2026-2050. Safe Skies, Sustainable Future. Available at: https://www.icao.int/about-icao/Council/Pages/strategic-plan-2026-2050.aspx.
10 International Transport Federation (2023). ITF Transport Outlook 2023. Paris: OECD Publishing. DOI: https://doi.org/10.1787/b6cc9ad5-en.

coordinated approach with Connected, Cooperative and Automated Mobility (CCAM) solutions. The aviation, automotive, railway, and wider mobility sectors must collaborate closely to establish standards for data exchange, digital infrastructure, and safety and security protocols. Real-time communication between eVTOLs and ground-based autonomous vehicles will be crucial for smooth transfers and the efficient use of shared infrastructure. By creating a holistic mobility ecosystem, cities and regions can unlock the full potential of UAM and ground-based mobility solutions, fostering greater efficiency, safety and service convenience.

Despite the promising outlook of IAS, deployment faces several challenges. One primary issue involves multi-level governance and regulatory coordination. Effective IAS deployment requires aligning city-level policies with national and international aviation frameworks, as well as cross-sectoral systems interoperability. Safe and efficient IAS operations require integration into airspace operations and the international harmonization of regulations and relevant standards. Fragmented regulations and inconsistent safety and security standards can hinder technological progress and erode public trust.

Another critical challenge lies in developing the necessary physical and digital infrastructure. Establishing vertiports and vertipads, managing low-level airspace IAS traffic, and integrating urban air traffic management and communication systems with ground-based intelligent transport systems and CCAM networks requires substantial investment. Ensuring consistent data standards, safety and security protocols is crucial for reliable, safe and secure mobility services.

On the societal front, engaging a wide range of stakeholders is essential for the responsible deployment of IAS. This involves addressing environmental, security and noise concerns, and ensuring societal embracement through transparent stakeholder engagement and real-world testing in living labs settings. Societal embracement entails a positive impact for society as a whole and is nurtured through transparent stakeholder engagement and real-world testing in living labs settings.

To realize the full potential of UAM, stakeholders in both the aviation and ground mobility sectors must work together to build an integrated, interoperable and efficient mobility ecosystem. This involves aligning standards, investing in shared infrastructure and embracing digital transformation. By overcoming challenges related to regulation, social acceptance and technology through a collaborative, cross-sectoral approach, cities and regions can unlock the opportunities presented by IAS.

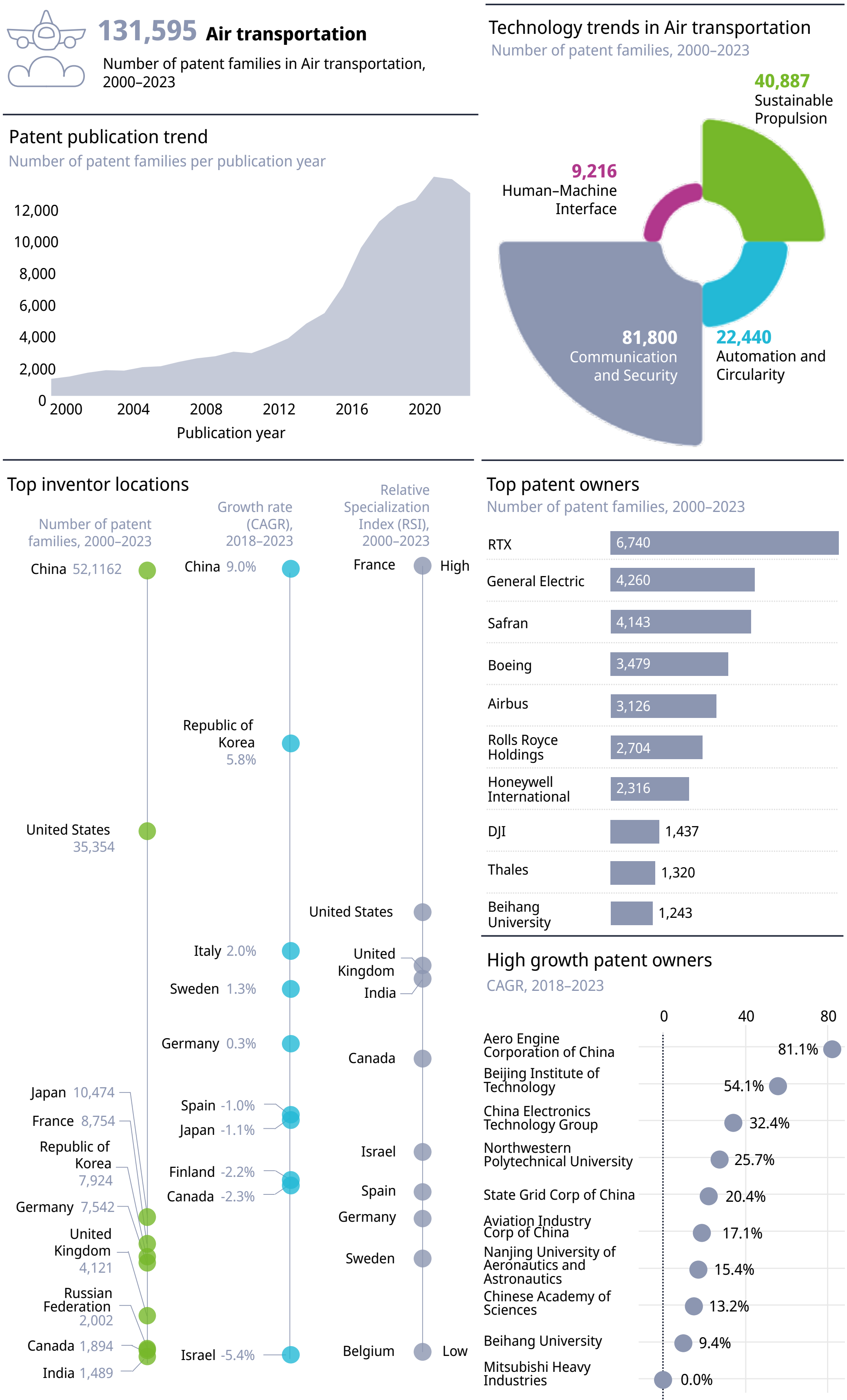
Environmental sustainability is a core principle in the development and deployment of IAS. To genuinely contribute to environmental stewardship, IAS must incorporate sustainable development practices throughout its entire ecosystem. This includes adopting life-cycle assessment strategies that consider end-of-life reuse, sourcing and responsible production methods. By integrating zero-emission propulsion systems and prioritizing energy-efficient operations, IAS can contribute to an improved and sustainable transportation network in urban and regional environments.

Sustainable IAS extends beyond only environmental considerations. Collaborative, cross-sectoral initiatives are required to ensure sustainable development practices that nurture and safeguard its positive societal impact in alignment with the principles and best practices of the United Nations Sustainable Development Goals (SDGs). This includes addressing societal dimensions such as inclusivity, accessibility and equitable access to mobility services.

As urban centers evolve, so too must our approach to mobility and other city operations and services. With the right policies, technology and infrastructure, IAS can improve the way we live and move in populated areas, by creating smarter, safer, more secure and more sustainable cities for the future.

A snapshot of the patent landscape in Air transportation, highlighting historical patenting activity, technology trends, key locations and top filers

Figure 4.9 Exploring the patent landscape in Air transportation

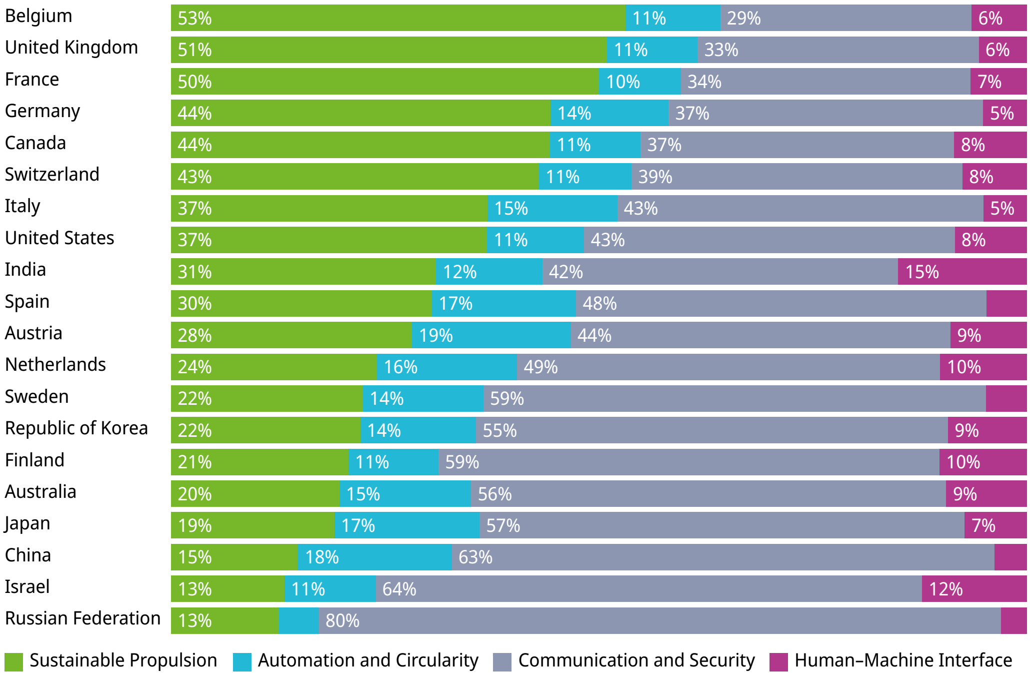


Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

The majority of Air transport patents from Belgium and the United Kingdom focus on Sustainable Propulsion technologies, whereas the Russian Federation, Israel and China prioritize Communication and Security technologies

Figure 4.10 Research priorities of the top 20 inventor locations in Air transportation, 2000–2023

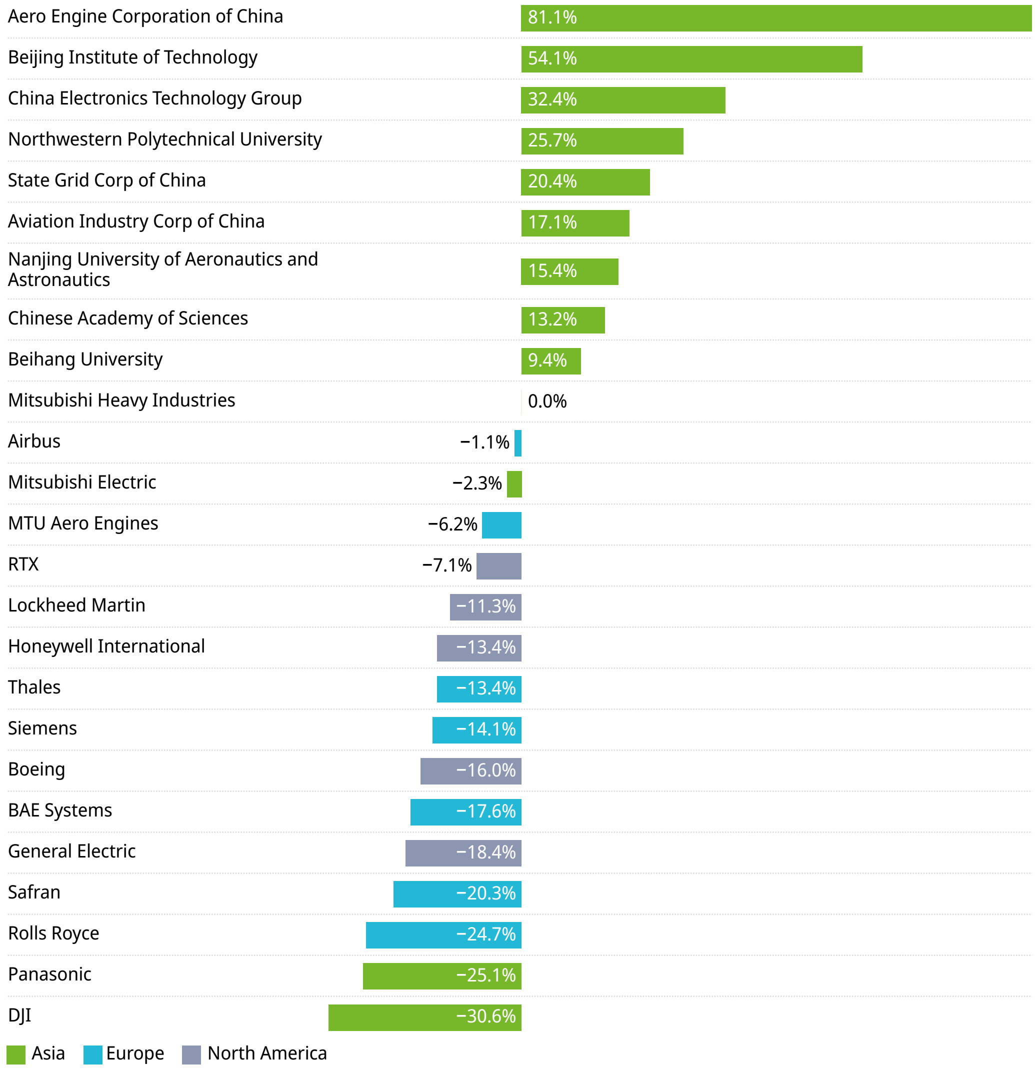


Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Figure 4.10 highlights global trends in Air transportation technologies, with Sustainable Propulsion technologies dominating in much of Europe, including in Belgium, the United Kingdom, France, Germany and Switzerland. Communication and Security technologies are important across the board, with a strong focus here in the Russian Federation, Israel and China.

Chinese patent owners exhibit strong recent growth in Air transport patents, in stark contrast to the growth of other top patentees in recent years

Figure 4.11 Compound annual growth rate (CAGR), 2018–2023, of the top 25 patent owners in Air transportation



Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024

A stark contrast in the growth of the top patent owners in Air transportation is shown in Figure 4.11, with Chinese institutions like Aero Engine Corporation of China AECC leading with an 81% increase, while prominent North American and European companies such as Boeing (–16%), Rolls-Royce (–24%) and Safran (–20%) experiencing reduced growth. With other Chinese patent owners also exhibiting high growth rates, this indicates a recent shift in innovation and investment momentum toward China and also the possible knock-on consequences of the COVID-19 pandemic on the most established players in the aviation industry. [11]

11 McKinsey (2022). Taking stock of the pandemic's impact on global aviation. McKinsey & Company. Available at: www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/taking-stock-of-the-pandemics-impact-on-global-aviation.

Artificial intelligence will change the shape of airports – Devin Liddell, Futurist

Airports today are shaped like a dumbbell. One end of the dumbbell is for ticketing and checked bags. The opposite end is where the gates are located, along with restaurants and shops. The thin middle between the two ends is for security screening, separating the "landside" of the airport from its "airside."

This airport shape has become more pronounced in the last two decades, mainly because of enhanced security screening apparatus.[12] But artificial intelligence is poised to subvert that shape: first by creating new ways for people to interact with existing airport infrastructure; then by challenging the traditional landside–airside barrier; and, finally, by enabling all-new design approaches to the physical and digital footprints of airports. Here's how those changes will unfold.

Five years from now: early negotiations with infrastructure

Airports have historically told you what they are doing. A giant flight information display system or a series of gate announcements is the airport broadcasting its operations. What you are doing as a passenger is extracting relevant information and maneuvering those operations. This power dynamic between what an airport is doing and what a passenger is doing is changing and becoming far more collaborative. At Seattle-Tacoma International Airport (SEA), for example, passengers can make "spot saver" appointments[13] for security screenings, skipping the lines; or passengers parking their vehicles can use an automated parking guidance system[14] to find open spots faster. In each instance, the airport is improving its efficiency by allowing passengers to interact with infrastructure more directly.

Add five years to these types of innovations, and it's easy to imagine even more personalized interactions with existing airport infrastructure: SEA's automated parking guidance system will integrate with passengers' AI-powered hearables and wearables for personalized voice-based interactions. Extending the same level of integration to airport partners, such as restaurateurs and ground transportation providers, will position the airport as a broker of services and enable passenger queries such as "What restaurants in concourse B have tables available right now?"

10 years from now: disrupting the landside/airside barrier

Artificial intelligence is at the heart of autonomous vehicles. Autonomous vehicles are also the single biggest future disruptor to contemporary airport operations, for two big reasons. First, they will erode parking–garage revenues, as these fleets begin conveying more and more passengers to the airport. Second, autonomous vehicles are secure and surveilled. Riders are authenticated as they access the vehicle and the vehicle itself is outfitted with cameras and microphones for monitoring and communicating with riders. Built-in characteristics such as these make autonomous vehicles a logical way for security screening to occur on the way to the airport. In other words, autonomous vehicles are next-generation, AI-powered security checkpoints.

Screening onboard autonomous vehicles presents some interesting operational possibilities for airports and airlines. If passengers are screened while they are heading to the airport, they will arrive on the airside of an airport since that's the post-screening "secure" side. There are two potential airside destinations, and both could be used simultaneously. One is inside on the concourse or at the gates, the other is directly to the aircraft. Airport retailers and restaurateurs will be pleased by the former and distressed by the latter. With both, though, airports will have new opportunities to re-allocate space for different functions within their physical footprint.

12 US News (2021). An entire generation of Americans has no idea how easy air travel used to be. Available at:www.usnews.com/news/national-news/articles/2021-09-08/an-entire-generation-of-americans-has-no-idea-how-easy-air-travel-used-to-be.
13 See www.portseattle.org/SEAspotsaver.
14 Port of Seattle. Automated parking guidance system. Available at: www.portseattle.org/projects/automated-parking-guidance-system.

20 years from now: big, fun airports and smaller intermodal airports

What does it look like when a future airport uses AI to manage its security screening and baggage handling offsite and transports passengers directly to aircraft? Existing airports will fill with fun those spaces previously devoted to lining up and waiting. That's right: the permanent decline of business travel, [15] the resilience of leisure travel, [16] and retailers and restaurateurs competing with direct-to-aircraft transportation in the future will put an emphasis on entertainment experiences. These big spaces will be filled with big things, and there are already precedents for where this is headed. Singapore's Jewel Changi Airport features the world's largest indoor waterfall and 240,000 square feet of indoor gardens. [17] Amsterdam Airport Schiphol offers free 24/7 access to Rijksmuseum Schiphol, [18] a rotating exhibit from the Netherlands' most famous museum. Munich Airport in Germany has hosted indoor surfing events [19] and high-ropes courses. [20]

Brand-new airports will focus on designing within a smaller physical footprint from the start. Combined with new forms of smaller and quieter aircraft, [21] there will be opportunities to bring airports and urban cores closer together, which will better integrate commercial aviation into rail networks and city transit systems. Since AI will enable the remote operation of air traffic control systems, there will also be opportunities for "pop-up" airports [22] that support population booms in places without traditional airports [23] and flex to meet the ups and downs of seasonal demand or a special event.

Though it is not obvious now and won't be obvious in retrospect, the diverse shapes and digital footprints of these future airports 20 years from now will have a shared origin in the expansion of AI technologies today.

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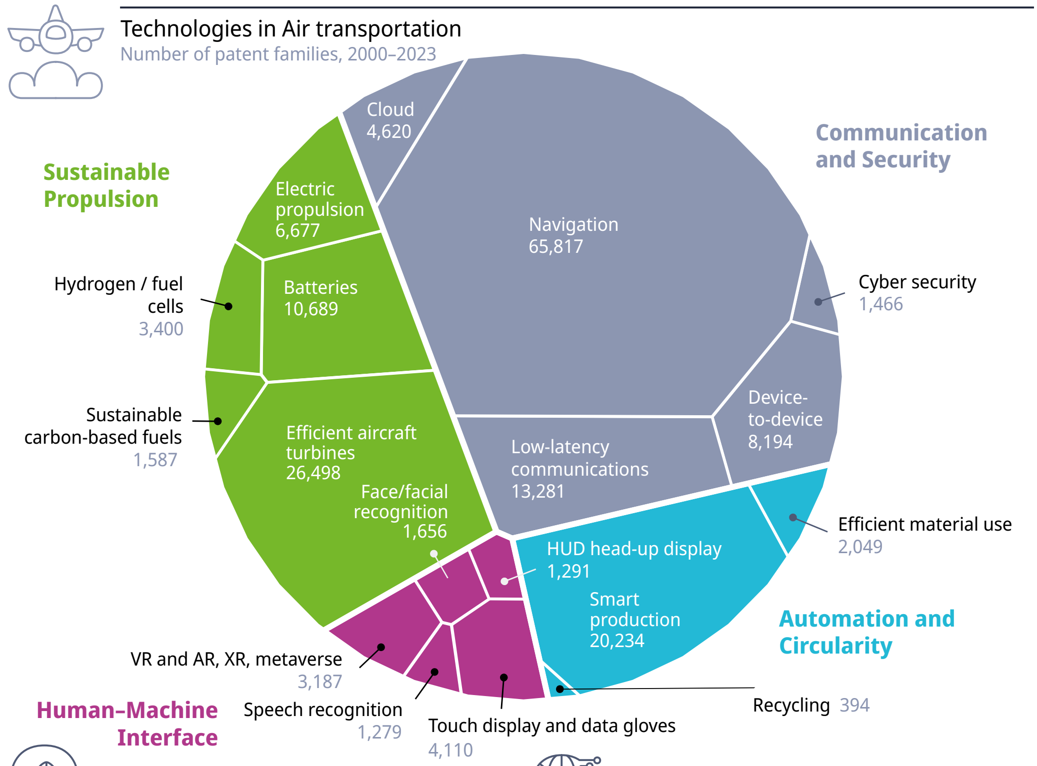
15 Forbes (2023). Business travel will never bounce back to pre-pandemic levels, studies say. Available at: www.forbes.com/sites/suzannerowankelleher/2023/04/24/business-travel-comeback/?sh=30f2206c44b2.
16 Marketplace (2023). Leisure travel is back: Business travel is not. Available at: www.marketplace.org/2023/04/25/leisure-travel-is-back-business-travel-is-not.
17 The Dirt (2019). Singapore's new garden airport. Available at: https://dirt.asla.org/2019/04/08/singapores-new-garden-airport.
18 Schiphol. An artistic start to your journey. Available at: www.schiphol.nl/en/at-schiphol/discover/facilities/rijksmuseum.
19 Surfer (2015). Surf culture: Surfing in the Munich Airport. Available at: www.surfer.com/blogs/surfing-in-the-munich-airport.
20 The Points Guy (2022). A new way to hang around between flights: Munich Airport's high-ropes course. Available at: https://thepointsguy.com/news/munich-airport-ropes-course.
21 Tech Crunch (2023). Wisk Aero starts flight testing electric autonomous aircraft in Los Angeles. Available at: https://techcrunch.com/2023/10/06/wisk-aero-starts-flight-testing-electric-autonomous-aircraft-in-los-angeles.
22 Dezeen (2022). Urban-Air Port designs "world's first urban airport" for flying cars and drones. Available at: www.dezeen.com/2022/04/20/air-one-urban-airport-electric-flying-cars-drones.
23 FP (2023). Demography is destiny in Africa. Available at: https://foreignpolicy.com/2023/08/26/demographics-africa-sub-sahara-population-boom-growth-aging-gender-inequality-climate-change.

A snapshot of the patent landscape in Air transportation in each of the four technology trends, highlighting key locations and top filers

Figure 4.12 Exploring the patent landscape in Air transportation in the four technology trends



Megatrend: Sustainability | Megatrend: Digitalization

Top inventor locations (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human-Machine Interface
United States 15,151	China 11,151	China 39,421	United States 3,450
China 9,235	United States 4,658	United States 17,769	China 2,330
France 4,722	Japan 2,256	Japan 7,545	Japan 964

High growth locations (CAGR, 2018–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human-Machine Interface
China 9.1%	Republic of Korea 10.8%	Italy 8.4%	Germany 2.0%
Republic of Korea 4.7%	India 6.6%	China 8.1%	Republic of Korea 0.8%
Japan 3.3%	China 1.5%	Republic of Korea 5.9%	China −3.9%

Highly specialized locations (Relative Specialization Index, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human-Machine Interface
France 0.79	France 0.49	France 0.46	India 0.68
United Kingdom 0.59	United States 0.28	Israel 0.3	France 0.66
United States 0.52	India 0.27	United States 0.28	United States 0.53

Top patent owners (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human-Machine Interface
RTX 4,974	Boeing 1,000	Boeing 2,165	Honeywell International 401
General Electric 3,783	DJI 536	Airbus 1,621	RTX 325
Safran 3,671	Airbus 476	Honeywell International 1,453	Thales 271

Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Figure 4.12 highlights four key technology trends driving the aviation industry's evolution. Geographically, while China and the United States are leaders across all four technology trends, certain locations demonstrate high growth in specific areas. The Republic of Korea shows significant progress in Automation and Circularity, Italy in Communication and Security, and Germany in HMI technologies. France stands out as the most specialized location across nearly all technological fields, largely because of the impact of French-based multinationals such as Airbus and Safran. In terms of key industry players, Boeing and Airbus are significantly active in Automation and Circularity together with Communication and Security technologies, while Raytheon Technologies (RTX) focuses on advancements in Sustainable Propulsion and HMI technologies.

A more detailed deep-dive analysis of patenting in Air transportation can be found in the technical annex "Future of Transportation in the Air."

Space transportation

Space transportation is a critical component of the global transportation system, involving the movement of people, goods and satellites beyond Earth's atmosphere using rockets and spacecraft. It plays a crucial role in scientific exploration, global communication and economic activity, providing satellite deployment, space station resupply and space tourism. The demand for satellite services is increasing, driven by advancements in technology and the need for global connectivity. However, efforts to decarbonize the space transport sector are essential for reducing emissions and achieving sustainable space exploration. Sustainability and Digitalization are key trends transforming the future of space transport, driven in particular by Communication and Security technologies, but with Sustainable Propulsion likely to be an increasing area of interest going forward. The adoption of these technologies will help create a more sustainable and efficient space transportation system, capable of meeting future demand while at the same time minimizing environmental impacts.

Could space innovation revolutionize global transportation? – Driss El Hadani, United Nations Office for Outer Space Affairs (UNOOSA)

The space transportation sector is rapidly evolving, driven by technological advancements that are making space activities more accessible, affordable and innovative. The rise of reusable launch vehicles pioneered by companies like SpaceX, Blue Origin and Rocket Lab are reducing the cost of launching payloads into orbit, by enabling multiple launches to be made from the same vehicle. This shift is opening the door to a wider range of activities in space, fostering growth within sectors such as satellite deployment, space exploration and research.

Another major advancement is the development of on-orbit servicing and refueling technologies. Companies like Northrop Grumman are creating solutions that enable satellites to be repaired, refueled or recycled while still in orbit. This technology extends the lifespan of satellites and reduces the need for frequent new launches, thus optimizing space operations. In addition, efforts in space mining and in situ resource utilization (ISRU) are progressing. Such technologies aim to extract resources from asteroids, the Moon and Mars, supporting sustainable space operations and future colonization. ISRU will allow for the extraction of essential resources like water and oxygen, reducing dependence on Earth-based supplies.

In terms of propulsion, electric and nuclear propulsion systems are under development, promising faster and more efficient travel within the solar system. Electric propulsion, such as ion thrusters, and nuclear thermal propulsion are expected to reduce travel time to destinations like Mars, enhancing exploration and enabling human settlement beyond Earth. Additionally, the growth of space activities is driving the need for space logistics and supply chains, which includes spaceports, refueling stations and manufacturing hubs. Companies are exploring ways to establish such infrastructure to support ongoing operations beyond Earth.

We are also seeing the demand for small satellite launches increase. The miniaturization of satellites and the growing need for global communication, Earth observation, and Internet of

Things (IoT) networks are driving this demand. As a result, new small launch vehicles and ride-sharing opportunities have emerged, making it easier to deploy constellations of satellites.

Space tourism is an emerging industry, with companies like Virgin Galactic and SpaceX at the forefront. These companies are bringing space travel closer to private citizens through suborbital flights offering a brief experience of space. Future plans include even more ambitious endeavors such as orbital hotels and lunar flybys.

Lastly, I believe that hypersonic travel and point-to-point space transport could revolutionize global transportation. Hypersonic vehicles, capable of flying at speeds many times faster than the speed of sound, could drastically reduce travel time between distant locations on Earth. For example, such vehicles could enable intercontinental flights in under an hour, by briefly exiting the Earth's atmosphere before re-entering at high speed. This technology has the potential to transform industries that rely on rapid transportation such as logistics, military operations, high-priority business travel and emergency services. Hypersonic travel could establish a new paradigm for global connectivity, shrinking the world and enabling more seamless global interaction.

To ensure that these revolutionary space transportation innovations realize their full potential in global transportation, UN bodies such as the Committee on the Peaceful Uses of Outer Space (COPUOS) must continue to play a crucial role in setting global standards, prioritizing safety, and addressing emerging challenges. By fostering international cooperation and adaptable regulations, we can unlock the full potential of space innovations to transform global transportation and improve connectivity worldwide.

After stagnating throughout the 2000s, global patenting activity in Space transport technologies has accelerated significantly since 2011 (Figure 4.13). Between 2011 and 2023, the number of inventions has increased sixfold from around 1,400 to almost 9,000 published patent families in 2023, a compound annual growth rate (CAGR) of about 8% between 2000 and 2023 and of about 15% between 2010 and 2023. In total, the patent search identified more than 67,000 inventions in the field of Space transport since 2000.

There are two main reasons for this increase. First, the emergence and rapid growth of private companies venturing into space in recent years has transformed space exploration, which was once dominated solely by government agencies.[24] These new entrants tend to fall into one of two categories: non-space companies, particularly large ICT companies such as Google or Facebook, expanding their activities and building on the synergies between ICT and space applications; and new space companies, such as SpaceX, which use private and/or public funding to initiate innovative business models and address new space markets or present existing space markets with disruptive solutions.[25] The emergence of these private companies is leading the Space sector toward a more business- and innovation-oriented scenario, often referred to as “New Space.”[26] This trend also enables public actors to consider more ambitious partnerships with industry and to better share costs and risks with the private sector.

Second, a resurgence of the international space race, with new entrants such as China, India and Japan investing heavily in Space technologies, has also been a driver of innovation activity. For example, Chinese startup LandSpace Technology plans to soon launch reusable rockets using a similar approach to SpaceX, while India aims to begin a series of flight tests for eventual crewed spaceflight in 2025.[27] Moreover, Japan succeeded in a lunar landing in 2024, becoming only the fifth country to make it to the surface of the Moon.[28]

24 See https://medium.com/techcrate/the-rise-of-private-companies-in-space-exploration-revolutionizing-the-final-frontier-71d0a273b419.
25 ESPI (2017). The Rise of Private Actors in the Space Sector. Vienna: European Space Policy Institute. Available at: www.espi.or.at/wp-content/uploads/2022/06/ESPI-report-The-rise-of-private-actors-Executive-Summary-1.pdf.
26 EPO (2021). Cosmonautics: The Development of Space-related Technologies in Terms of Patent Activity. Munich: European Patent Office. Available at: https://link.epo.org/web/patent_insight_report-cosmonautics_en.pdf.
27 Nikkei Asia (2024). Space race to heat up in 2024 as Japan, China, India reach for the stars. Available at: https://asia.nikkei.com/Business/Aerospace-Defense-Industries/Space-race-to-heat-up-in-2024-as-Japan-China-India-reach-for-the-stars.
28 East Asia Forum (2024). Asia’s ascendance in the new international space order. Available at: https://eastasiaforum.org/2024/05/22/asias-ascendance-in-the-new-international-space-order.

A snapshot of the patent landscape in Space transportation, highlighting historical patenting activity, technology trends, key locations and top filers

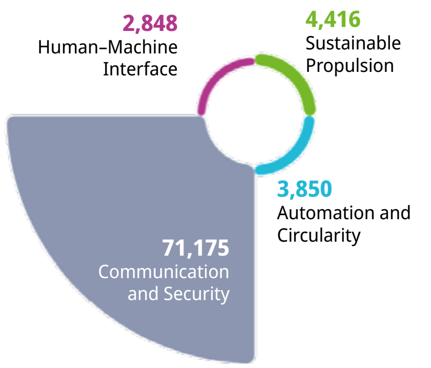
Figure 4.13 Exploring the patent landscape in Space transportation

74,712 Space transportation

Number of patent families in Land transportation, 2000–2023

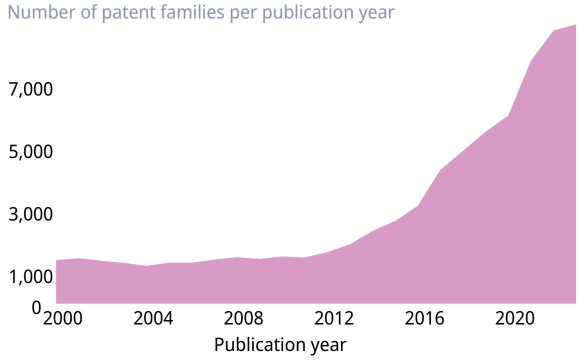
Technology trends in Space transportation

Number of patent families, 2000–2023

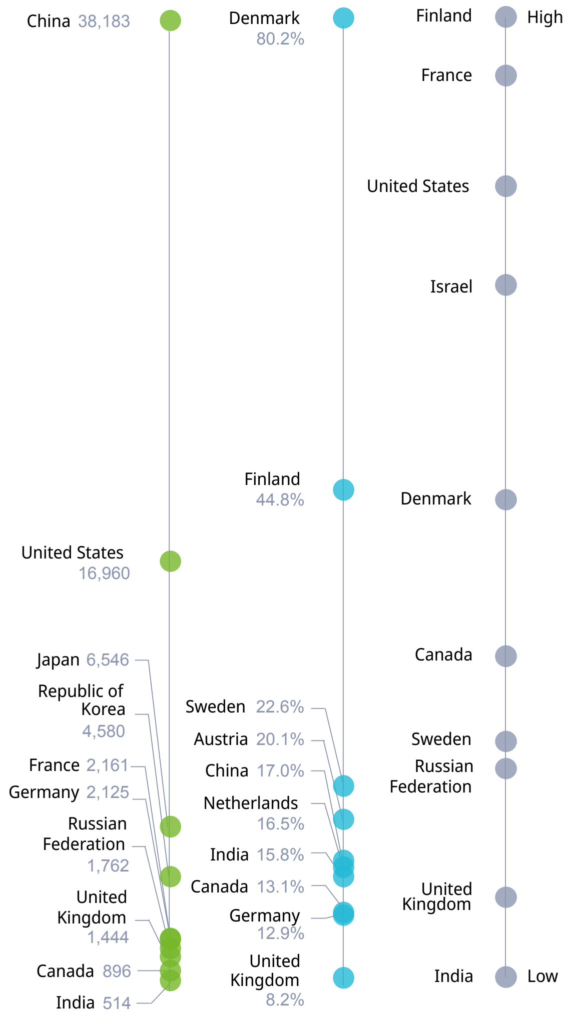


Patent publication trend

Number of patent families per publication year

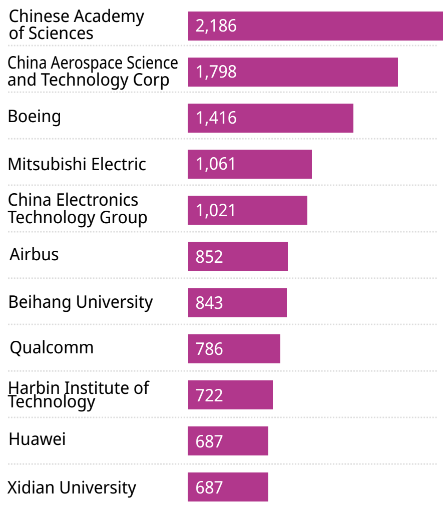


Top inventor locations



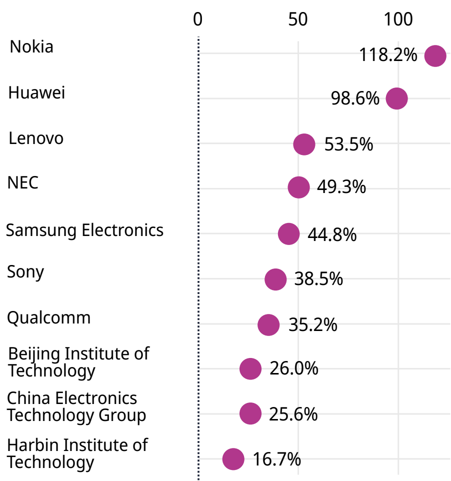
Top patent owners

Number of patent families, 2000–2023



High growth patent owners

CAGR, 2018–2023



Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Patenting in Space transport technologies is hugely dominated by inventions relating the Communication and Security (Figure 4.14), but patent growth has been highest in Automation and Circularity technologies with a compound annual growth rate (CAGR) of 15% between 2000 and 2023 and a sharp acceleration since 2011. Patent growth in the other technology trends has been in the high single digits between 2000 and 2023.

Intellectual property and outer space

A lot has happened since the 1950/60 "space race." New governments have taken an active role in space exploration and the private sector has become increasingly interested in exploring and pursuing commercial interests. What was once only a reality for a few countries is now populated by many players, including the governments of India, Brazil and South Africa, as well as big companies including SpaceX, Blue Origin and Virgin Galactic, to name just three.

Presently, there are signals that space could again become a central issue for countries worldwide. Therefore, space policy and governance could attract attention once again, especially considering that within the next 10 years the space economy is projected to reach USD 1.8 trillion in value[29] as space-enabled technologies advance and continue to become more important to our daily lives. Research and development in fields such as pharmaceuticals is currently being conducted at space stations, and several industries are already entering into exclusive arrangements with pioneering private firms involved in space tourism to supply services exclusively. This creates emerging and novel marketplaces for goods and services tailored for use in outer space. Consequently, companies may decide to actively seek intellectual property (IP) protection for such innovative items, thereby broadening the reach of the global IP ecosystem.

The relationship between IP and outer space activities has attracted attention in the past. In 2004, WIPO prepared an issue paper for an Organisation for Economic Co-operation and Development (OECD) futures project on the commercialization of space and the development of space infrastructure.[30] More recently in 2023, the International Trademark Association (INTA) also issued a report on IP and space.[31]

The prevailing international space governance framework is administered by many decentralized entities, including by governmental institutions, treaties, agreements, national laws and policies. Five primary treaties[32] delineate the foundational principles and values guiding human activities in space, which collectively uphold that space is a shared domain for all humanity; space pursuits ought to yield benefits for all nations; no single nation may assert or claim sovereignty in space; space and celestial bodies should be utilized for peaceful purposes; nations must register every launch and assume responsibility for related activities, whether commercial or governmental; assistance should be rendered to astronauts in distress; and, lastly, international peace and cooperation shall serve as the bedrock of all space endeavors. Notably, these treaties do not explicitly address IP matters.

Recent agreements and guidelines[33] have begun to incorporate references to IP[34] that, together with private contracts, provide additional clarity on the IP-related issues that could arise as space exploration and commercialization continues to be linked to Earth.[35]

29 WEF (2024). Space is booming: Here's how to embrace the $1.8 trillion opportunity. World Economic Forum (weforum.org). Available at: www.weforum.org/agenda/2024/04/space-economy-technology-invest-rocket-opportunity.
30 WIPO (2004). Intellectual Property and Space Activities. Issue paper prepared by the International Bureau of WIPO. World Intellectual Property Organization. Available at: www.wipo.int/documents/d/patents/docs-en-topics-outer-space-ip_space_wipo-contribution_oecd_2004.pdf.
31 INTA (2023). INTA Research: Intellectual Property in Space. White Paper. International Trademark Association (inta.org). Available at: www.inta.org/perspectives/inta-research/intellectual-property-in-space-white-paper.
32 United Nations Outer Space Treaty (1967); United Nations Rescue Agreement (1968); United Nations Liability Convention (1972); United Nations Registration Convention (1975); United Nations Moon Agreement (1979).
33 Including International Space Station (ISS) Treaty/Intergovernmental Agreement (1998), the UN COPUOS (2019) Guidelines and the NASA Artemis Accords (2020).
34 For example, Article 21 of the International Space Station (ISS) Treaty/Intergovernmental Agreement (1998) states that *"Subject to the provisions of this Article, for purposes of intellectual property law, an activity occurring in or on a Space Station flight element shall be deemed to have occurred only in the territory of the Partner State of that element's registry, except that for ESA-registered elements any European Partner State may deem the activity to have occurred within its territory. For avoidance of doubt, participation by a Partner State, its Cooperating Agency, or its related entities in an activity occurring in or on any other Partner's Space Station flight element shall not in and of itself alter or affect the jurisdiction over such activity provided for in the previous sentence."*
35 For example, article VIII of the Outer Space Treaty establishes that the state of registry retains jurisdiction and control over space objects and personnel launched into outer space.

Looking toward the potential future directions of space exploration, it is possible to imagine that eventually space activities may no longer be linked to Earth. With some proponents exploring the possibility of making humanity a multiplanetary species, the question of the role of IP in fostering innovation and creativity in that future therefore becomes important and provides a platform to think about the fundamental issues of IP in light of the unique circumstances of space. For example, will the concepts of territoriality and jurisdiction apply differently to space colonies? What kind of enforcement and dispute resolution mechanisms will be required? Or what kind of exceptions and limitations will strike the right balance between protecting the interests of right holders, third parties and the public.

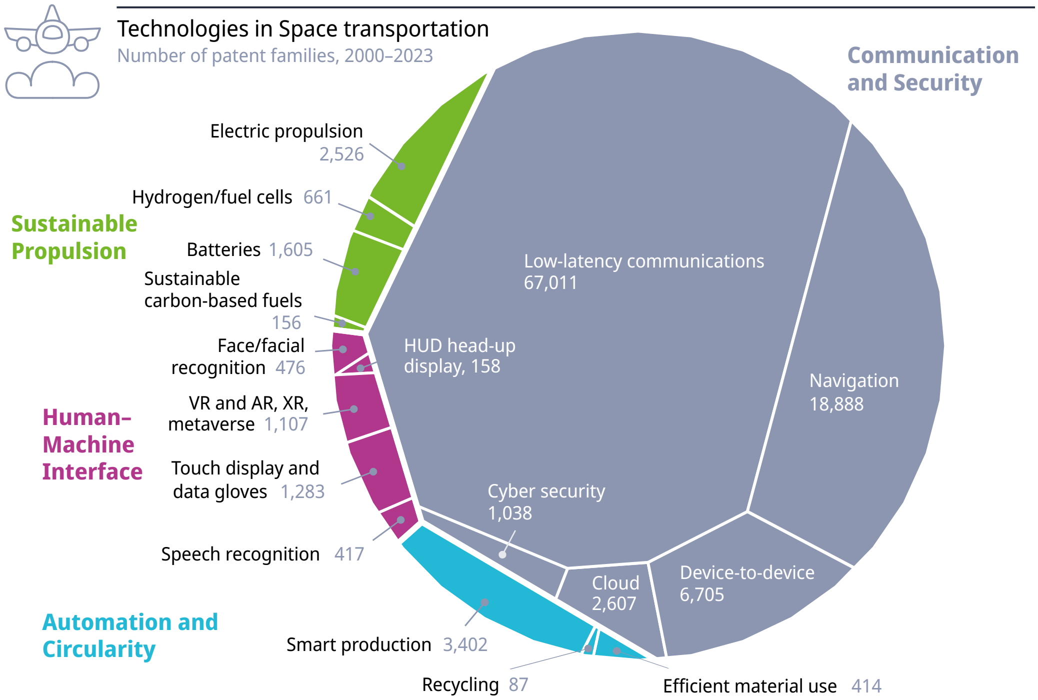
As we see signals that in the long term space will become an ever greater reality, it will be crucial to ensure that the IP system continues to foster creativity, innovation and collaboration and accompanies humanity on its venture ever further into the cosmos as it pushes at the technological boundaries of space exploration.

In the Space industry, patents are not always the primary focus for those undertaking research and development (R&D) and innovation activities. In part, this is because of the unique nature of the Space industry, which often values rapid advancement, collaboration, and secrecy over the protection of IP. Space missions and projects often involve collaborations between multiple countries, companies, and government agencies, where shared knowledge and open innovation are prioritized over proprietary ownership. Many organizations, especially private companies, keep new developments as trade secrets instead of patents to maintain competitive advantage without disclosing sensitive information. This approach allows for more flexibility in innovation and helps safeguard strategic technologies crucial to national security and commercial success in space. Nonetheless, patenting in the space industry is rapidly increasing as more and more private companies enter the field, and so analysis of patenting in space is increasingly becoming of interest. [36]

36 See, for example, the European Patent Office's (EPO) platform on space related inventions – https://www.epo.org/en/searching-for-patents/technology-platforms/space-innovation– and the space-related patent landscape reports from the EPO (https://link.epo.org/web/business/patent-insight-reports/en-propulsion-systems-for-space.pdf) and the Canadian Intellectual Property Office (https://ised- isde.canada.ca/site/canadian-intellectual-property-office/en/patents-space-highlighting-innovation- canadian-space-sector).

A snapshot of the patent landscape in Space transportation in the four technology trends, highlighting key locations and top filers

Figure 4.14 Exploring the patent landscape in Space transportation in the four technology trends



Megatrend: Sustainability | Megatrend: Digitalization

Top inventor locations (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
China 1,468	China 2,019	China 36,631	China 700
United States 1,265	United States 1,037	United States 16,134	United States 1,280
Japan 532	Japan 233	Japan 6,195	Japan 355

High growth locations (CAGR, 2018–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
United Kingdom 43.1%	France 14.9%	Finland 47.6%	Germany 5.9%
China 20.6%	India 14.9%	Sweden 22.4%	China −0.8%
Republic of Korea 10.8%	China 10.6%	China 17.1%	United States −5.5%

Highly specialized locations (Relative Specialization Index, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
France 0.55	Canada 0.41	Finland 0.38	Israel 0.61
Russia Federation 0.44	United States 0.4	France 0.34	United States 0.59
United States 0.42	Australia 0.33	United States 0.32	Australia 0.58

Top patent owners (Number of patent families, 2000–2023)

Sustainable Propulsion	Automation and Circularity	Communication and Security	Human–Machine Interface
Boeing 173	China Aerospace Science and Technology Corporation 194	Chinese Academy of Sciences 2,120	Alphabet 83
Airbus 133	Boeing 126	China Aerospace Science and Technology Corporation 1,624	Sony 57
China Aerospace Science and Technology Corporation 90	Northwestern Polytechnical University 112	Boeing 1,304	Boeing 43

Note: Only the top 20 inventor locations are included in the calculations for the compound annual growth rate (CAGR) and the Relative Specialization Index (RSI).

Source: WIPO, based on patent data from EconSight/IFI Claims, October 2024.

Does SpaceX have patents?

SpaceX has become a major innovator in space research through its innovative approach to spacecraft and rocket design. The company has achieved numerous milestones, including the development of the Falcon rockets, which have lowered the cost of access to space. SpaceX's Dragon spacecraft was the first commercial vehicle to deliver cargo to the International Space Station (ISS), and SpaceX now carries astronauts to the ISS as part of NASA's Commercial Crew Program. [37] With ambitious goals such as the Starship project [38] to colonize Mars, SpaceX continues to push the boundaries of space technology and exploration.

SpaceX has filed only a low double-digit number of patents for its research activities in the space technologies analyzed, which mainly cover satellite technologies but not rocket technology. The company appears to prefer to use trade secrets rather than patenting its technology. Company founder Elon Musk argued in 2012 that SpaceX does not want to allow competitors to use published SpaceX patents "as a recipe book." [39] However, there are risks to keeping trade secrets, as they can be leaked or stolen. In addition, trade secret protection does not protect against independent discovery or reverse engineering. [40]

A more detailed deep-dive analysis of patenting in Space transportation can be found in the technical annex "Future of Transportation in Space."

37 SpaceX. Space station: Transporting humans to the orbiting laboratory in the sky. Available at: www.spacex.com/humanspaceflight/iss.
38 SpaceX. Starship: Service to Earth orbit, Moon, Mars and beyond. Available at: www.spacex.com/vehicles/starship.
39 Wired (2012). Elon Musk's mission to Mars. Available at: www.wired.com/2012/10/ff-elon-musk-qa.
40 Patent Forecast (2021). Where are SpaceX's patents? Its trade secrets strategy is fraught with peril. Available at: www.patentforecast.com/2021/05/27/where-are-spacexs-patents-its-trade-secrets-strategy-is-fraught-with-peril.

5 Emerging technologies in transportation

Emerging technologies refer to new, innovative technologies in the early stages of development or adoption, often representing advancements that could significantly impact industries, societies, or economies. In this chapter we identify and analyze two emerging technologies in each of the four principal transport modalities of Land, Sea, Air and Space.

In addition to our analysis of the four key technology trends, we identified and performed in-depth analysis on two emerging technologies in each of the four principal transport modalities. Emerging technologies refer to new, innovative technologies in the early stages of development or adoption, often representing advancements that could significantly impact industries, societies, or economies. Such technologies are usually characterized by their potential for rapid growth, their transformative capabilities and an ability to create new opportunities or disrupt existing systems. Emerging technologies are closely tied to technological trends. This is because trends often signal the direction in which technology is evolving and highlight areas where emerging innovations may soon have a significant impact.

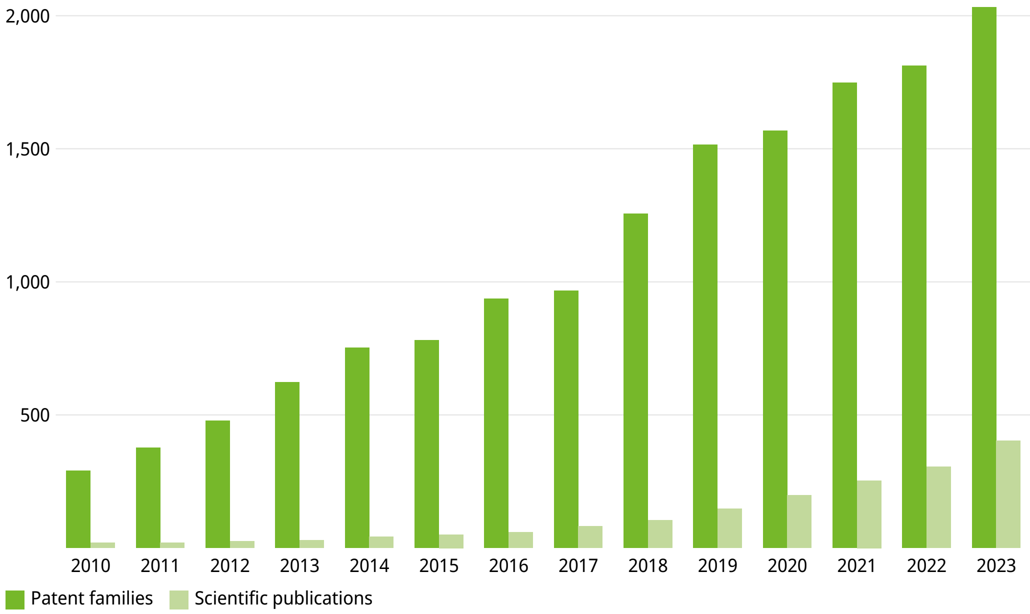
In this report, we identified emerging technologies by analyzing 'weak signals' – that is, subtle indicators that reveal potential future directions in technological development. These signals were gathered from several key sources. We examined patent activity dynamics, in which trends in patent filings indicated areas of growing innovation and interest. Additionally, we reviewed statements and strategic plans from companies and organizations so as to uncover their priorities and technological focus areas. Political considerations, such as government policies, funding priorities and strategic documents, also provided valuable insights, reflecting public investment trends and societal priorities. Through this analysis, we gained an early perspective on potential technological directions, identifying relevant examples of emerging technologies that are poised to become significant trends. Our selection represents a list of very promising emerging technologies, but it cannot be an exhaustive list of all emerging technologies due to the space constraints of this report.

Land: solid-state batteries

Solid-state batteries (SSBs) represent a significant advancement in battery technology, offering several key benefits over traditional batteries. They are particularly relevant for both freight and passenger vehicles owing to their potential to enhance performance and safety. The core benefits of solid-state batteries include enhanced safety, higher energy density, longer lifespan and fast charging capability. However, solid-state batteries currently have several limitations, including challenges regarding commercial-scale production, complex and costly manufacturing processes, and maintaining the stability of solid electrolytes and their interface with electrodes.

Research and patenting activities in solid-state batteries have grown significantly in recent years but remain a niche within the broader field of battery technologies

Figure 5.1 Development of global scientific publications and patents in solid-state batteries, 2010–2023

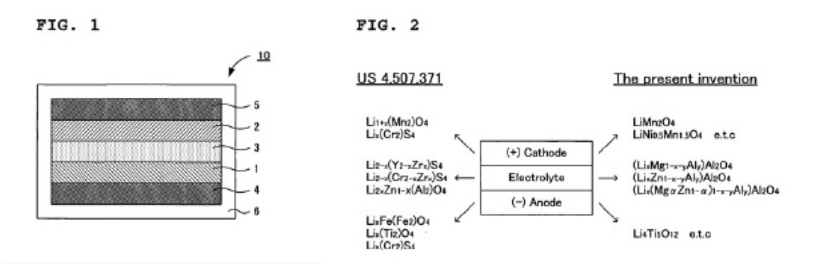


Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Figure 5.1 shows the number of scientific publications and patents related to solid- state batteries published annually from 2010 to 2023. The data show a steady increase in the number of scientific publications over time, but patenting activity is more prevalent. Analysis of patents for solid-state batteries also reveals an increase, with the number of published patent families having grown from only 290 back in 2010 to over 2000 in 2023. However, compared to overall patenting activity in battery technologies, solid-state batteries have remained a niche research area, so far.

Technology at a glance

Toyota's patent (WO2011142150A1) outlines a solid-state battery featuring an ionic conductor with a spinel structure. The ion conductor has a structure wherein which it is easy for ions to move, thereby increasing ion conductivity, and a greater electrochemical stability than other structures on the market. The design aims to improve battery performance and stability by optimizing the conductor's composition and integration.



Source: WO2011142150A1

The use of a spinel structure ionic conductor, specifically tailored with lithium, magnesium, zinc and aluminum, can enhance the ionic conductivity and stability of a battery. By incorporating these materials into the cathode, anode, and solid electrolyte layers, the design addresses key challenges in solid-state battery development, such as improving energy density, safety, and longevity. If successfully implemented, this could lead to more efficient, durable, and commercially viable solid-state batteries.

Standardization is crucial for emerging and disruptive technologies – Thor Myklebust, SINTEF

Standardization has become increasingly important in all domains, especially within the automotive sector. I believe this is because of the growing role of autonomy and other emerging and disruptive technology (EDT) requiring standardized interfaces in order to harness their potential and assure safety, security, consistency and interoperability across different applications and systems.

The European Union's AI Act (Regulation 2024/1689) is a significant step toward creating a harmonized legal framework for artificial intelligence (AI) systems, while promoting innovation and maintaining high safety standards, transparency and fundamental rights. By adhering to standardized approaches, manufacturers and stakeholders can assure consistency and trustworthiness across various AI applications, which in turn supports a competitive and secure environment for AI deployment across different domains. The EU's innovative approach to regulations, whereby compliance with relevant harmonized standards[1] is considered to be compliance with relevant legislation, simplifies the process for manufacturers and stakeholders. This approach not only reduces the complexity of regulations, but also encourages the adoption of standardized practices, thereby promoting safety, security, consistency and interoperability across different applications and systems.

And how is a standard developed?

It involves a structured process in which key documents are created at different stages to guide manufacturers and other stakeholders in complying with regulatory requirements and gaining international acceptance. This process often begins with a Technical Report (TR) that provides early guidance, which is then refined into a Technical Specification (TS) or Publicly Available Specification (PAS), and finally, an International Standard (IS), once the technology is mature.

This approach allows for a flexible, minimum viable product (MVP) strategy for manufacturers, enabling the release of useful guidelines early on in the process to support stakeholders and regulatory compliance.

For standards to become harmonized within the European Union (EU), they must include legal requirements and be listed in the *Official Journal of the European Union* (*OJEU*) to assure alignment with EU legislation. This is exemplified by the railway applications standard EN 50126-1:2017, which is a harmonized standard for EU Directive 2008/57/EC for railway interoperability.

Global engagement in EDT – including AI standards – promotes innovation, protects intellectual property (IP) and assures responsible AI development. Common standards simplify AI integration across markets, reducing barriers and encouraging adoption. They also help protect IP by providing clear technical guidelines, aiding in patenting and preventing disputes, and fostering investment in EDT, including AI.

Emphasizing transparency and ethics, standards build trust between users and regulators, facilitating acceptance while safeguarding privacy.

International collaboration aligns EDT (including AI) and governance approaches, eases cross-border operations and fosters a sharing of innovation that meets global needs. Understanding standards and standardization has a crucial role to play in the future across the transportation industry. Such an understanding ensures that systems and technologies operate together seamlessly, which is vital for safety and interoperability in environments where different nations and organizations collaborate, such as in international maritime operations, air traffic management and space exploration.

1 A harmonized standard within the European Union (EU) is a standard developed by a recognized European Standards Organizsation (ESO): CEN, CENELEC, or ETSI. Such as standard is created following a request from the European Commission to one of these three organizsations. Manufacturers, other economic operators, and conformity assessment bodies are then able to use harmonized standards to demonstrate that products, systems, services, or processes comply with the relevant EU legislation.

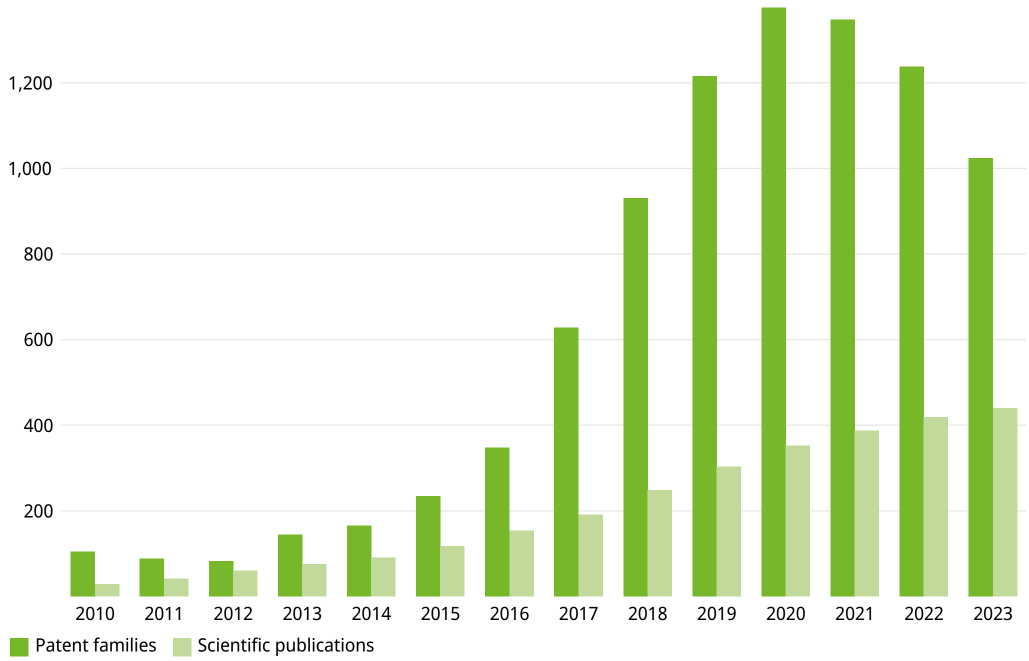
However, there is still a lack of funding and research dedicated to developing relevant harmonized standards, especially those relating to the EU AI Act. This is a challenge that needs to be addressed, if the safe, secure and ethical deployment of AI systems is to assured.

Land: platooning

Platooning represents a significant advancement in Land transportation technology, enabling multiple vehicles to travel closely together at high speed, controlled by automated driving systems and vehicle-to-vehicle (V2V) communication. This technology involves forming a convoy of vehicles, typically trucks, led by a vehicle that is manually driven, with the vehicles following autonomously controlled so as to maintain a close distance and synchronize movement. The technological benefits of platooning include improved fuel efficiency, enhanced safety and greater road capacity. However, platooning also faces several challenges and limitations, including the need for a reliable V2V communication system, regulatory and legal hurdles, and the requirement for consistent road infrastructure to support automated driving technologies.

Research and patenting activities relating to platooning have grown rapidly since 2014, but patent publications have declined in recent years

Figure 5.2 Development of global scientific publications and patents in platooning, 2010–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Figure 5.2 indicates that scientific research on platooning has gained momentum over the past decade, especially from 2018 onward. This growth reflects a growing recognition of platooning as a viable and beneficial technology for the future of Land transportation. Continued research and development in this area are expected to further enhance the feasibility and implementation of platooning systems on a broader scale. Primary research topics in platooning have included advancements in V2V communication technologies, the development of robust control algorithms and the assessment of platooning's impact on traffic dynamics and fuel efficiency. Researchers are also exploring the integration of platooning into other intelligent transportation systems (ITS) to create more cohesive and efficient road networks.

Patent activities related to platooning have been increasing too, reflecting both a growing interest and investment in this technology. Major automotive and technology companies are actively filing patents for various aspects of platooning, including V2V communication protocols, control systems and safety mechanisms. Between 2014 and 2023, the number of published patent families per year increased from less than 200 to over 1,000. However, patent families have declined over recent years, after having peaked at almost 1,400 in 2020.

Technology at a glance

A recent development from DAF (US10948928B2) relates to a method for autonomously guiding motor vehicles in a platooning formation, using steering and headway controllers coupled with lateral and front distance control systems. It involves dual lane side detectors, which could be 2D or 3D laser scanners or integrated cameras in modified side mirrors, providing the image data needed to maintain vehicle alignment and proximity to the lead vehicle. Additionally, these systems are capable of complex tasks such as arbitrating between lateral distance, a pre-set forward look-ahead point and data from other sensors such as radar for comprehensive vehicle steering and navigation control.

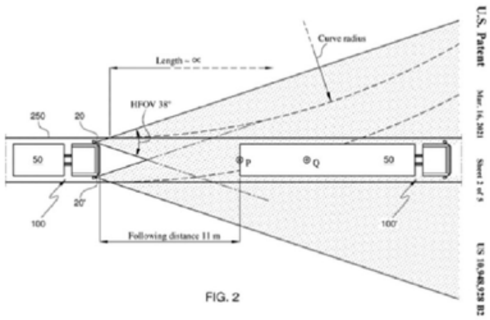


FIG. 2

Source: US10948928B2

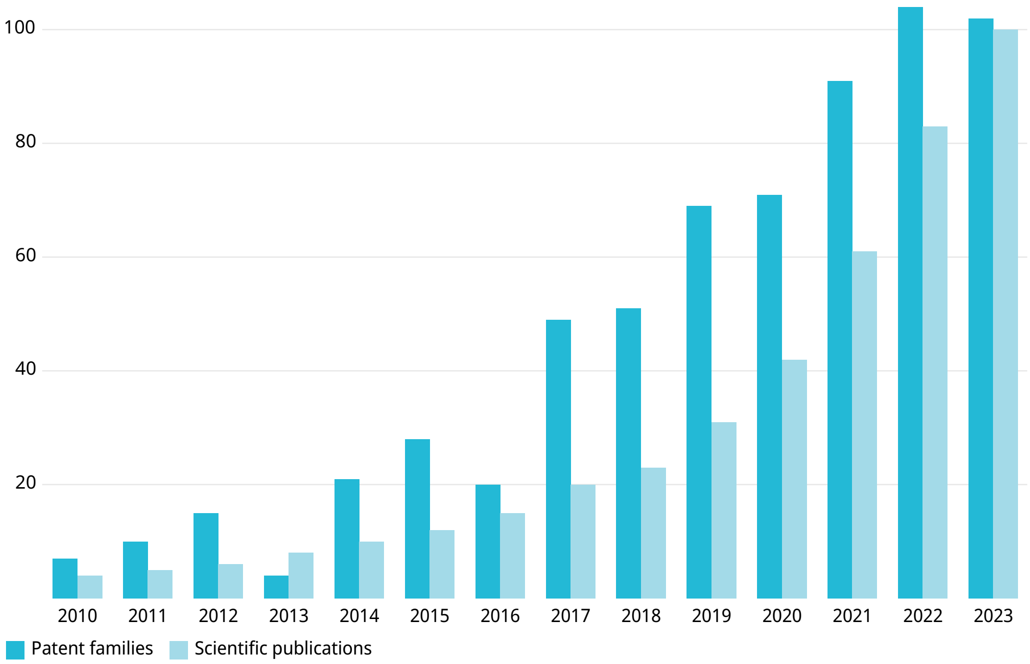
Sea: smart ports

Ports are vital components of the global logistics network and have undergone a significant transformation driven by economic, socioeconomic, political and environmental factors. The need for Sustainability and Digitalization has led to the emergence of smart ports that align with Industry 4.0 innovations for long-term sustainability. A smart port is characterized by highly efficient, autonomous and technologically advanced operations, achieved through the adoption of cutting-edge technologies such as AI, Big Data, IoT and blockchain. These technologies enable automation, the optimization of logistics flow and enhanced efficiency. The definition of a smart port emphasizes the role of innovation and automation in boosting performance, including intelligent management of operations for maximum efficiency and minimal environmental impact. The integration of Industry 4.0 technologies in smart ports aims to achieve port facility automation and autonomy, improve resource utilization and enhance overall port operations.

The scientific community's engagement with smart ports has also seen a noticeable uptick in research activity (Figure 5.3). Since 2016, there has been a marked increase in peer-reviewed journal articles focusing on various aspects of smart port technologies. This growing academic interest highlights a shift toward exploring and addressing the complex challenges and opportunities that smart ports present. Such research endeavors are often foundational, paving the way for practical applications and technological breakthroughs. The examination of the patent landscape reveals that patenting activity in the field of smart ports has picked up speed in recent years. The number of published patent families has increased from only 20 in 2016 to over 100 in 2023.

The growth of research and patenting activities relating to smart ports is driving the transformation of ports toward digitalization and intelligent management

Figure 5.3 Development of global scientific publications and patents in smart port technologies, 2010–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

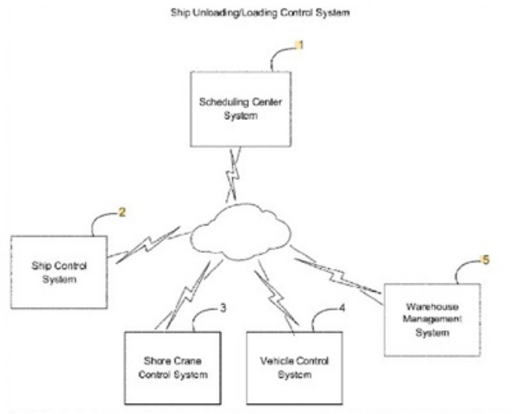
The smart port projects in Shanghai[2], Busan[3], Rotterdam[4], and Hamburg[5] exemplify the cutting-edge integration of technology in maritime logistics. These projects highlight how the future of port operations is changing. They leverage innovations from recent patents, including advanced automation, data analytics, and IoT, to enhance efficiency, safety, and sustainability, signaling a transformative leap toward the digitalization and intelligent management of maritime trade hubs.

As the demand for more efficient, sustainable, and safer sea transport grows, the move towards smart ports is becoming not just a trend but an imperative. The industry is witnessing a shift away from traditional port operations and toward a future where ports are not just transit points, but intelligent systems that can think, decide, and act autonomously, thus marking a new era in maritime technology and logistics.

Technology at a glance

The invention detailed in a patent application filed by Shanghai Tusen Weilai Artificial Intelligence Technology Co., Ltd. (US20200140242A1) is a system designed to control the unloading and loading of ships using advanced technology. It includes a ship loading and unloading control system and related apparatuses, which work together to optimize the entire process. This system is aimed at improving the efficiency and coordination of maritime cargo handling, by utilizing scheduling systems, shore crane control systems, and vehicle control systems. It relies on technologies such as AI, big data, and automated scheduling and task management integrating with warehouse management systems to streamline operations.

2 South China Morning Post (2023). Shanghai port operator aims to expand capacity of its automated terminal at Yangshan and help shippers reduce waiting time and costs. Available at: www.scmp.com/business/china-business/article/3234313/shanghai-port-operator-aims-expand-capacity-its-automated-terminal-yangshan-and-help-shippers-reduce.
3 American Journal of Transportation (2023). Port of Busan will open its first automated terminal In 2023 using Korean cranes. Available at: www.ajot.com/insights/full/ai-port-of-busan-will-open-its-first-automated-terminal-in-2023-using-korean-cranes.
4 Port of Rotterdam (2024). Port of Rotterdam developing into major digital platform. Available at: www.portofrotterdam.com/en/to-do-port/futureland/the-digital-port.
5 Hamburg Port Authority (2024). HPA goes smartPORT. Available at: www.hamburg-port-authority.de/fileadmin/user_upload/150422_tl_messe_lowres.pdf.



Source: US20200140242A1

This invention highlights the technological components of a smart port, aligning as it does with the concept of port automation and efficiency central to the idea of a smart port. By integrating various technological components like scheduling systems and crane control systems, it enables ports to manage loading and unloading processes more autonomously and efficiently. This integration facilitates real-time data sharing and decision-making, both key elements of a smart port's operations, leading to increased productivity, reduced operational costs and enhanced safety – all characteristics that define smart port capabilities.

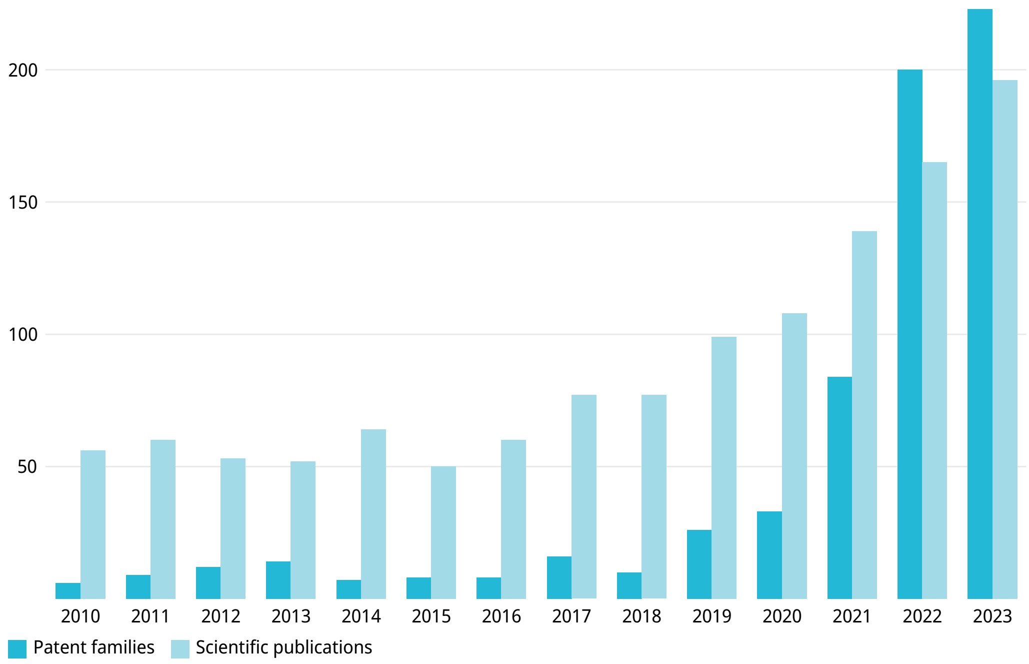
Sea: ammonia as a marine fuel

Ammonia (NH_3) is a potential alternative marine fuel composed of nitrogen and hydrogen that can power ships and produces only minimal carbon emissions. Its high energy density, established production and transportation infrastructure, and successful engine conversions make it a viable candidate for decarbonizing the maritime industry. There are two types of ammonia: green ammonia, produced using renewable energy sources, and blue ammonia, produced using natural gas with carbon capture and storage technology. Among the benefits of ammonia as a marine fuel are its carbon-neutral potential, global availability and existing infrastructure. However, challenges, such as toxicity, safety concerns, economic viability and production challenges, need to be addressed before mainstream adoption. Ongoing research and technological innovations aim to overcome these challenges and enhance ammonia's viability as a marine fuel.

Ammonia as a marine fuel has increasingly become a focal point of scientific research, driven by an urgent need for sustainable and low-carbon alternatives in the maritime industry. Over the past decade, there has been a significant rise in the number of publications exploring the potential of ammonia, reflecting its growing importance in the global push toward decarbonization. This surge in research is not only widespread across multiple countries, but gaining momentum, as indicated by the substantial increase in the number of studies, particularly in the last few years (Figure 5.4). Patenting activity in the field of ammonia as a marine fuel has recently picked up speed. From only 33 patent families in 2020, the number of patent publications had jumped to over 200 by 2023.

Research and patenting activities into ammonia as a marine fuel have increased significantly, reflecting its growing importance in driving global decarbonization efforts

Figure 5.4 Development of global scientific publications and patents in ammonia as a marine fuel, 2004–2023



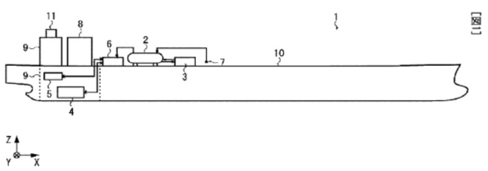
Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Technology at a glance

Because vessel designs play a vital role in respect to leakage and concerns regarding the toxicity of ammonia, Nihon Shipyard Co., Ltd., a prominent Japanese shipbuilding company, is actively involved in the development of ammonia-powered ships as part of its effort to contribute to the global transition toward greener maritime transport. A recent Nihon Shipyard patent (WO2023210390A1) from 2023 for an ammonia-fueled ship is a significant innovation that addresses the critical safety challenges associated with using ammonia as a marine fuel, particularly its toxicity and corrosiveness. The design features an advanced engine room layout, in which the space is divided into several distinct areas based on the varying risks of ammonia gas leakage. These areas are separated by specially designed partitions that prevent the spread of ammonia gas, effectively containing any potential leaks within specific zones and minimizing the risk to other parts of the ship.

Partitions can be configured to either completely seal off these areas or to only partition the upper spaces, depending on the level of risk and operational requirements. Additionally, in an emergency, the partitions are designed to allow water to pass through, providing a means of controlling or neutralizing leakage.

The engine room is thoughtfully divided into specific regions, for example, one that houses the generator using ammonia as fuel and another that contains the engine. A key safety feature is the inclusion of a designated area through which ammonia fuel does not pass, which further reduces the risk to critical components of exposure.



Source: WO2023210390A1

To further mitigate the risk of ammonia leakage, the patent proposes that areas with a higher likelihood of leakage are maintained at a lower internal pressure compared to those at lower risk. The pressure differential helps contain any ammonia gas within the high-risk zones and preventing it from spreading. Each region is also equipped with an independent ventilation system designed to effectively remove ammonia from the air. The ventilation systems are optimized with exhaust ports positioned higher than air supply ports thus ensuring the efficient removal of lighter ammonia gas, complemented by ventilation fans that actively manage air circulation.

This patent plays a crucial role in advancing the use of green ammonia as a marine fuel, by addressing the significant safety concerns that have been a barrier to its adoption. By implementing these advanced safety features, Nihon Shipyard is making it feasible to safely operate ammonia-fueled ships, thereby supporting the broader transition to this zero-carbon fuel. As the maritime industry seeks to reduce its carbon footprint, innovations like this patent are essential for making ammonia a viable and safe alternative to traditional fossil fuels, facilitating the industry's shift toward sustainable energy sources.

Air: sustainable aviation fuel

Sustainable aviation fuels (SAFs) are produced from renewable resources, offering an alternative to conventional jet fuels derived from fossil fuel. Some examples[6] of SAFs are:

- Biofuels: these are made from organic materials such as plant oils, algae or agricultural waste. Examples include hydroprocessed esters and fatty acids (HEFA) derived from plant oils and Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), which is produced by converting biomass (e.g., wood or agricultural residue) into a synthetic fuel using the Fischer-Tropsch process.
- Alcohol-to-Jet (AtJ): this process converts alcohols, such as ethanol or butanol, into jet fuel. The alcohol is typically derived from renewable sources like corn or cellulosic biomass.
- Power-to-Liquid (PtL): this type of SAF uses renewable electricity (e.g., wind or solar power) to convert carbon dioxide (CO_2) and water into synthetic fuels, typically using a process called electrolysis and the Fischer-Tropsch synthesis.
- Camelina-based biofuels: camelina is a type of oilseed plant used to produce biofuel for aviation. It is seen as a promising feedstock, because it can be grown on land unsuitable for food crops.
- Algae-based biofuels: algae produce oils that can be processed into SAFs; and, since algae can grow in water without competing with food crops, it is considered a highly sustainable option.

SAFs currently account for less than 0.1% of all aviation fuels consumed. Increasing their use to 10% by 2030 is seen as crucial if the aviation industry is to achieve its sustainability goals.[7] SAFs can reduce lifecycle greenhouse gas emissions by up to 80% compared to conventional jet fuel and contribute to improved air quality and energy security. However, SAFs face limitations. They include higher production costs, technical challenges related to engine and infrastructure compatibility, and the need for a consistent supply of high-quality feedstock. Scaling up SAF production to commercial levels requires significant investment in biorefineries and infrastructure upgrades.

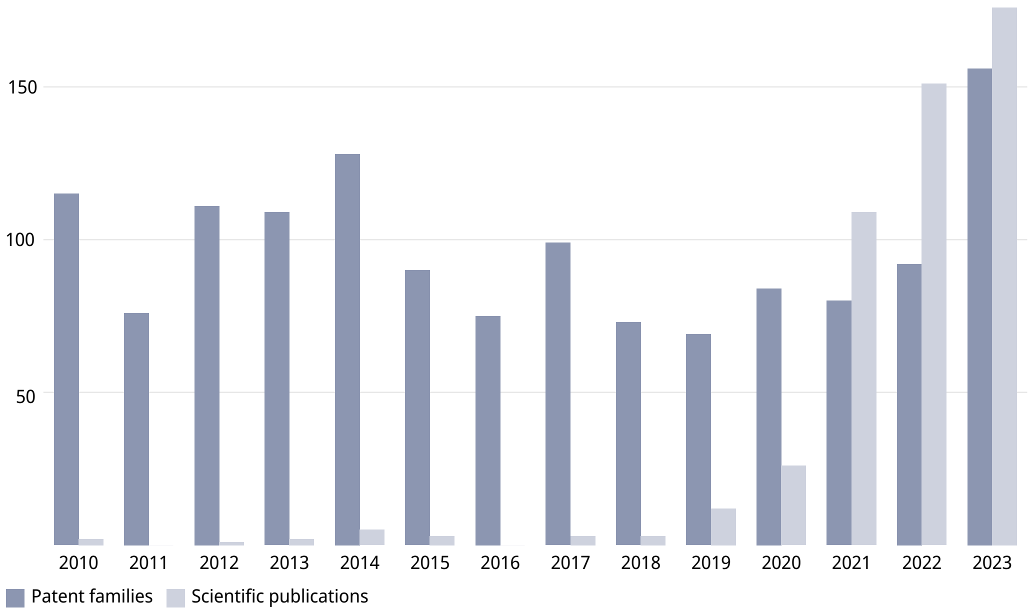
The scientific community has shown increasing interest in SAFs, as evidenced by the growing number of publications on the topic. Research focuses on improving production processes, assessing environmental impacts and enhancing the performance of SAFs in aviation applications. Figure 5.5 shows the number of scientific documents related to SAFs published annually from 2010 to 2023. The data show a steady increase in publications, with a significant surge starting around 2020. This trend indicates a growing interest in SAFs and their potential to transform the aviation industry. Patenting activity in the field of sustainable aviation fuels already increased at the end of the 2000s and peaked in 2014 with 128 patent families.

6 See, for example, What is SAF? International Air Transport Association, available at: www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-what-is-saf.pdf.
7 A&O Shearman (2023). Sustainable aviation fuel: On the ascent. Available at: www.aoshearman.com/en/insights/perspectives-on-energy-transition-in-emerging-markets/sustainable-aviation-fuel-on-the-ascent.

After plateauing at this level for a few years, patenting activity declined and did not pick up significantly until 2023 when it reached over 150 patent families.

Patenting activity for SAFs has remained steady since 2010, but scientific publications have seen significant growth starting in 2020

Figure 5.5 Development of global scientific publications and patents in sustainable aviation fuels, 2010–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Technology at a glance

The invention described in a patent from Topsoe (WO2022171643A1) involves an innovative method for producing sustainable aviation fuels (SAFs). This method focuses on using bio-based feedstocks, such as vegetable oils, and employs advanced chemical catalysts to optimize the conversion process. The goal is to enhance the efficiency of the feedstock-to-fuel conversion, resulting in a higher fuel yield and a reduced production costs.

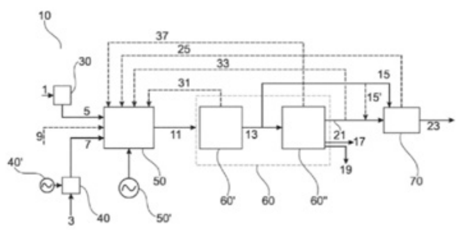


Fig. 1

Source: WO2022171643A1

Additionally, the SAFs produced using this method are designed to be compatible with existing aviation infrastructure and engines, requiring only minimal adjustments to fuel delivery systems. This approach aims to provide a commercially viable and environmentally-friendly alternative to conventional jet fuel, thereby reducing the aviation industry's carbon footprint and reliance on fossil fuel.

Air: urban air mobility

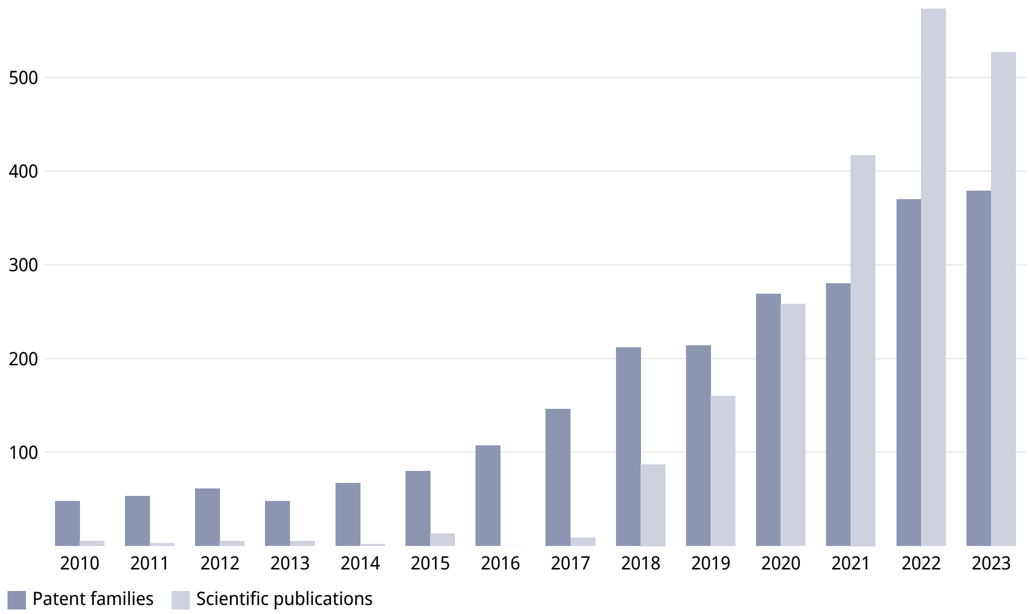
Urban air taxis, also known as VTOLs (vertical takeoff and landing aircraft), are a significant advancement in urban air mobility (UAM), aiming to alleviate urban congestion and reduce travel times in densely populated areas. There are various types of urban air taxis under development, including vectored thrust, wingless, lift plus cruise, and tilt rotor configurations. The adoption of urban air mobility can lead to reduced travel times, decreased urban congestion, lower emissions and has substantial economic benefits. However, challenges remain in terms of infrastructure development, regulatory frameworks, public acceptance and technical limitations, such as battery technology, flight safety and noise reduction.

The scientific community has shown increasing interest in urban air taxis, as evidenced by the growing number of publications on the topic. Research focuses on improving eVTOL technology, assessing environmental impacts, and enhancing the safety and efficiency of urban air mobility.[8]

Figure 5.6 illustrates the trends in scientific publications and patents relating to urban air taxis from 2010 to 2023. This shows a steady increase in publications, with a significant increase starting around 2017. This trend indicates a growing interest in urban air taxis and their potential to transform urban transportation. Patenting activity in the field of urban air mobility has picked up speed significantly over the last ten years. The number of global patent families has jumped from 67 in 2014 to almost 400 in 2023.

Research and patenting activities relating to urban air taxis have steadily increased, indicating growing interest and their potential to transform urban transportation

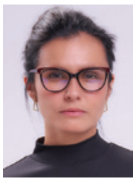
Figure 5.6 Development of global scientific publications and patents in urban air mobility, 2010–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

8 Rajendran S. and S. Srinivas (2020). Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. Transportation Research Part E: Logistics and Transportation Review, 143, 102090. DOI: https://doi.org/10.1016/j.tre.2020.102090.

Unlocking the skies for crewed VTOLs – Agnieszka Wiszowaty, Maviator Group



The European Union (EU) has recently taken a monumental step in the realm of air transportation with the introduction of new aviation regulations designed to accommodate vertical take-off and landing (VTOL) technology. With new regulations, including the European Commission Regulation (EU) 2024/1111 set to take effect in May 2025 and updated Special Conditions for small-category VTOL, the EU has laid a comprehensive foundation for integrating crewed VTOL aircraft into Europe's transportation ecosystem. In my view, these regulations are not only timely but transformative, enabling innovative air mobility (IAM) solutions to flourish under a robust and adaptable legislative framework.

What stands out for me is the inclusive and collaborative process undertaken by the European Union Aviation Safety Agency (EASA) in formulating these regulations. Over three years of consultation with industry stakeholders has ensured that the new framework reflects a balanced approach to safety, innovation and practical application. This openness to feedback and flexibility paves the way for diverse VTOL designs and operational models to thrive.

The new regulations define crewed IAM operations as the "safe, secure, and sustainable air mobility of passengers and cargo enabled by next-generation technologies integrated into a multimodal transportation system." This forward-thinking definition underscores the EU's commitment to shaping a future for air transportation that is both innovative and sustainable.

A pivotal aspect of these regulations is the creation of a new aircraft category: VTOL- Capable Aircraft (VCA). By distinguishing these vehicles from traditional rotorcraft and airplanes, the EU recognizes the unique advantages of VTOL technology, particularly its reliance on distributed propulsion systems, which utilize more than two propulsion units. This innovation not only enhances operational safety by spreading critical functions across multiple components but also sets a new standard for modern aviation design.

The new regulations implement unified rules for VTOL operations across the EU to ensure consistent safety standards. While this framework is justified during the initial stages of shaping the regulatory landscape, I believe it requires modifications and simplifications to better accommodate small VCAs and non-commercial flights.

Given the current absence of procedures for obtaining VCA pilot certification, the regulatory decision to allow commercial pilots with airplane or helicopter licenses to obtain VCA type ratings addresses the immediate need for qualified operators. At the same time, the establishment of standards for vertiports and designated "diversion locations" ensures that infrastructure development keeps pace with technological advancements. This integrated approach reflects the EU's commitment to making VTOL operations scalable and seamless.

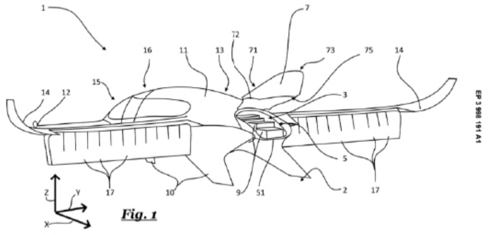
Looking ahead, as EASA gains experience and the IAM sector continues to expand, I anticipate further refinements to the regulatory framework, particularly the adoption of a more detailed common set of conditions for certification and Acceptable Means of Compliance and Guidance Material for VCA. I am particularly awaiting the introduction of simplified certification procedures for ultralight manned eVTOLs, which I believe will accelerate their market entry and stimulate innovation within this sector.

By creating a unified regulatory framework, the EU has provided much-needed clarity and fairness for manufacturers, operators and investors. These standards position the EU as a global leader in VTOL integration, advancing air mobility goals while aligning with broader objectives for accessible, sustainable and efficient transportation.

I am confident that this regulatory foundation will usher VTOLs into everyday transportation across Europe, unlocking the skies for a new era of air mobility. This visionary move sets a strong precedent for how regulation and innovation can coexist to drive progress. The EU is not only embracing the future of air transportation, but it is also setting a global standard for others to follow.

Technology at a glance

Recent developments from Lilium (EP3998191A1) include a vertical takeoff and landing (VTOL) passenger aircraft, emphasizing easy luggage access and energy efficiency. This VTOL aircraft combines helicopter-like capabilities for limited space takeoffs and landings with the high-speed and efficient cruising of conventional aircraft, aiming to reduce energy consumption, especially in electrically-powered eVTOL models. It includes a fuselage with a passenger cabin and a rear-accessible cargo bay, featuring an upward-opening door for efficient luggage loading without hindering passenger movement. The cargo bay is optimally positioned and sized to balance weight distribution and minimize aerodynamic drag. The design supports urban air taxi services, offering convenient regional mobility with sufficient luggage capacity and rapid access.



Source: EP3998191A1

Are eVTOLs just pure hype? – Robert Garbett, Drone Major Group

The electric vertical takeoff and landing (eVTOL) aircraft is creating quite a buzz! There are some people who think of it as something completely different from any other type of helicopter, manned or unmanned, but that is completely wrong. The eVTOL market can be looked upon as an evolution of the helicopter with such aircraft being managed the same way and flown the same way as a helicopter, even if they are made to look sleek and futuristic.

The eVTOL market can be separated into carrying passengers and carrying cargo. If we first look at the passenger market, aircraft are going to be manned and operated in exactly same way as a helicopter, unless it is a short jump along a very controlled route. Even if you could get a civil aviation authority to grant permission to fly commercially, you've got all sorts of other issues, including who's going to buy a ticket to sit in an aircraft controlled by a piece of software for which there is no certification system yet in place?

So, carrying passengers is what I call an aspiration. It is a brilliant idea, and it will eventually happen, but not until a long, long way down the line. We will still need a pilot, at least for the next 15 to 25 years. Getting to unmanned passenger vehicles will be more of a technology push than a market pull. It is still very expensive to build these electric aircraft. You will need a lot of certifications to assure safety, which will come at a huge cost so, besides the environmental argument, which is tenuous at best, it isn't clear what the advantage is compared to the manned helicopters of today.

Cargo, on the other hand, has a very promising future.

The key here will be creating something that is of benefit to society and shaping the narrative accordingly. A drone flying over a beach full of people will immediately have you thinking of it as an invasion of privacy, but if you are told it is from the local council and that it is surveying the area to ensure there is no sewage going into the sea, you are reassured and likely to be okay with it buzzing overhead.

I would not like to look up at a sky full of drones delivering pizzas or a pair of gloves to my house and causing visual and noise pollution. Due to the number of drones required, it will be extremely difficult to make it safe and commercially viable and it will most definitely not be socially acceptable. So, when we hear about such things happening, it is generally more of a publicity stunt.

If a delivery is to a remote location that is really hard to get to, people will be more likely to accept it as a beneficial solution. However, if the drone is delivering emergency medicine to somebody who is so sick that they can't leave their house or is enabling automation of cargo movement on the river Thames, thus reducing the number of trucks going through the middle of London, then not only does it become commercially viable, but also gets public buy in.

You must make sure you are engaging with the public, letting people know that those vehicles in the sky aren't invading your privacy, for example, by making them distinctive in some way. So, when you look up at the sky you would know that it is just one of those drones going about its everyday business and in so doing helping to reduce traffic.

There are huge opportunities within this industry to make a lot of money and also make a great difference to people's lives. For example, getting from a hub to a depot to a sub-depot along known routes that are low risk such as critical national infrastructure like roads or rail where you're not flying over people. You do need some infrastructure such as the "Digital Tethering" concept, which absolutely guarantees that an aircraft will not turn suddenly because its GPS has been confused and it's lost. Of course, you will need to ensure that all the data being collected is governed strictly according to local laws, and the digital infrastructure will have to follow the guidance set out in the relevant safety and quality standards for unmanned air systems.

So you've got to have the infrastructure; you've got to have the safety in the aircraft; and you're going to have to take it one route at a time and not imagine that you can fly anywhere you want, any time you need to. It's a tough business to make a success in due to the necessary legislative requirements but, those that do will be very successful.

Space: additive manufacturing in space

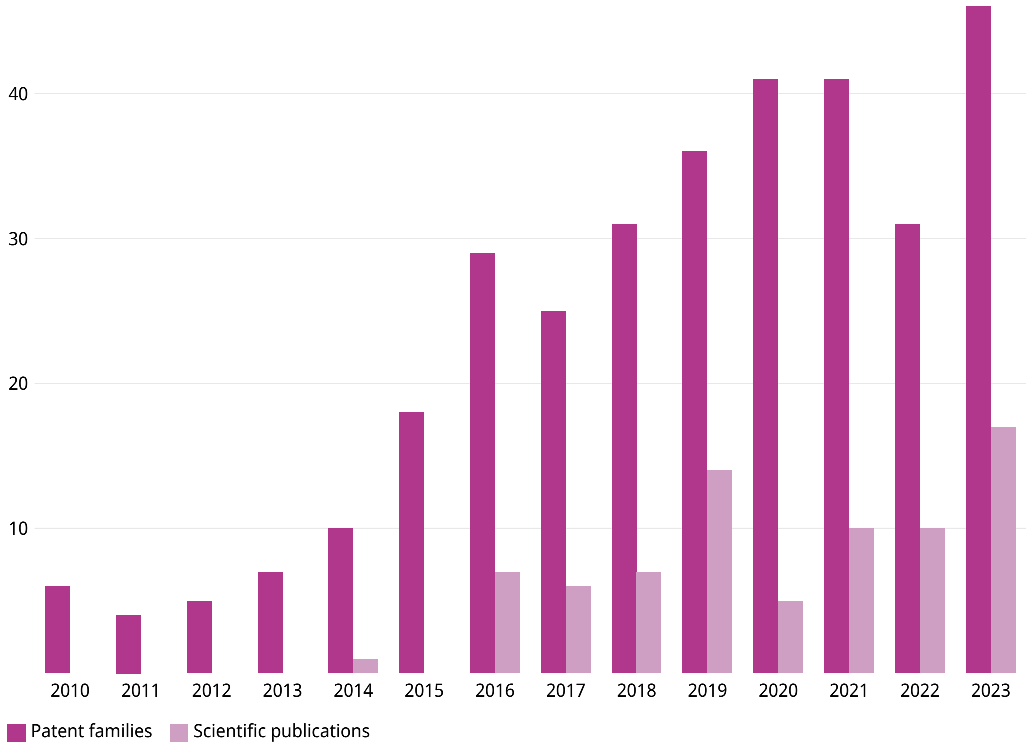
Additive manufacturing (AM) in space, also known as *in situ* manufacturing, is a process that creates objects layer by layer using locally available resources and adapting to the space environment's constraints. This technology aims to support long-term space missions, by reducing dependency on Earth-supplied materials and enhancing the sustainability of space exploration. AM in space allows for the creation of larger structures directly in space, bypassing limitations imposed by the size of launch vehicle fairings. It also significantly reduces costs, by allowing the production of necessary components on-site, minimizing the frequency and cost of resupply missions. Various additive manufacturing techniques are being developed and utilized in space, including polymer additive manufacturing, metal additive manufacturing and regolith-based manufacturing. The benefits of AM in space include reduced need to carry a large inventory of spares, cost savings, the creation of complex geometries and improved sustainability of exploration missions. However, challenges remain. Among them are ensuring materials printed in space have the same properties as those manufactured on Earth, adapting to unique environmental challenges, as well as integrating new manufacturing technologies into existing spacecraft systems.

The scientific community has shown increasing interest in AM in Space, as evidenced by the growing number of publications on the topic. Figure 5.7 shows an increase in the number of scientific documents published annually in the field from 2014 to 2023. This chart reveals several notable trends. Initially, the field experienced slow growth from 2014 to 2016, indicating the nascent stages of research and foundational studies during these years. The number of scientific publications began to rise significantly around 2016–2017, reflecting increased interest and early development efforts. This period likely marks the transition from exploratory research to more focused studies and early applications.

Patent analysis shows increasing patenting activity in recent times, suggesting a period of accelerated research and significant advancements, possibly driven by technological breakthroughs, increased funding, and heightened interest from both academia and industry. The number of published patent families has increased from only 10 in 2014 to 46 in 2023.

Additive manufacturing in space progressed from initial research (2014–2016) to early development (2016–2017), with recent patent activity indicating accelerated advancements

Figure 5.7 Development of global scientific publications and patents in additive manufacturing in space, 2010–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Technology at a glance

In 2019, BAE Systems developed an early additive manufacturing system for space. The invention (EP3527373A1) pertains to an advanced system for manufacturing articles in space, integrated into a space-based object, for example, a space vehicle or station. The core component is an additive manufacturing apparatus that uses supplied feedstock to produce various articles. This apparatus is supported by a feedstock storage module, ensuring a steady material supply, and a controller that manages manufacturing operations.

A key feature is the recycling module. This converts waste material into usable feedstock, enhancing sustainability and efficiency by minimizing waste and reducing the need for new materials. Additionally, the system includes a machining apparatus for further processing, with waste from both additive manufacturing and machining being recycled.

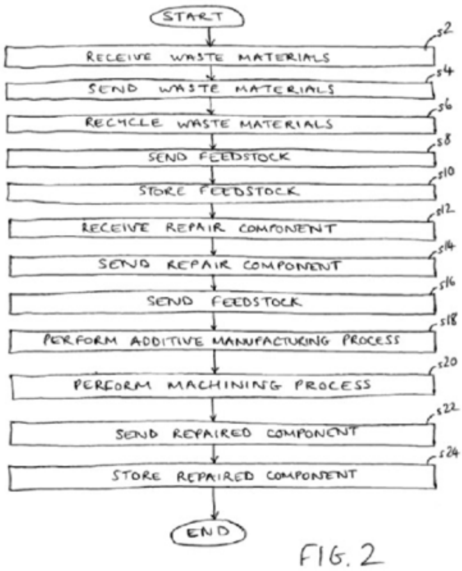


FIG. 2

Source: EP3527373A1

This space-based object can dock with other objects, allowing the exchange of waste materials and manufactured or repaired articles, facilitating resource sharing during space missions. A storage module holds articles for repair, which the manufacturing apparatus can then process, thus extending the life of critical components.

An inspection module assures the quality of manufactured articles, and the system can communicate with an Earth-based facility for data transfer and remote control. The manufacturing apparatus is versatile and capable of using wire, plastic or metal feedstock, making it adaptable for various needs. Designed to be autonomous or remotely controlled, this system represents a significant advancement in the field of in-space manufacturing, supporting long-term missions through improved efficiency and sustainability.

Additive manufacturing could define the future of space travel – Eujin Pei, Brunel University of London

Additive manufacturing will become more prevalent in the manufacturing of parts, not just in the space sector but overall. We will probably see it becoming more widespread and being adopted with confidence in space applications. The question is, how quickly?

The key challenge is certification. Standards and certifications are very important to assure that a part is reliable for operational use. We are seeing additive manufacturing being used in making small, non-critical parts. But to move on to making critical and bigger parts, I think the key is to adopt and implement standards quickly. That is when I think there is going to be a step change. There needs to be standards for manufacturing, testing and inspection, as well as certificates for quality assurance.

Another aspect is component traceability – from design to end-of-life, something like the European Union's proposed digital product passport. Then you can trace back if there is a failure. Or if there is no replacement, you can trace back to what process was used and who did what.

There was news recently of a metal part being produced at the International Space Station. This takes additive manufacturing in space a step further, up from just printing plastic parts. This is something that could be used on the Moon, or Mars or in space, say, using materials available on space bodies. However, we are not going to be mining on the Moon or Mars for a very long time. First, we need to prove everything works well. And for that we will need to carry all the raw materials from Earth. What you have with you is what you get.

As opposed to printing spare parts or components, there is the potential for additive manufacturing to be used to print parts that you want to take with you when you go into space, but maybe don't have the room. Or how about personalizing a space mission crew or even a space tourist's journey. When you are on site, you can simply pull up the design file and print it, be it a harness or a scientific instrument. This gives you the ability to react to your needs on demand.

To me, the most interesting materials are shape memory materials, which give you the ability to not just make a material, but by using some trigger for it to change its shape, say, a big complex solar panel that unfurls itself in space.

Although I still do not foresee this happening within the next 15 to 20 years, things may change within a shorter time, once you jump the certification hurdle.

Space: blockchain in satellite communications

Blockchain technology in satellite communication enhances security, efficiency, and management by utilizing decentralized digital ledgers, smart contracts and advanced encryption methods. It addresses critical security challenges, by providing a tamper- proof method of managing data and command transmissions, improving satellite network management efficiency and enabling the creation of secure and virtual trusted zones in space.

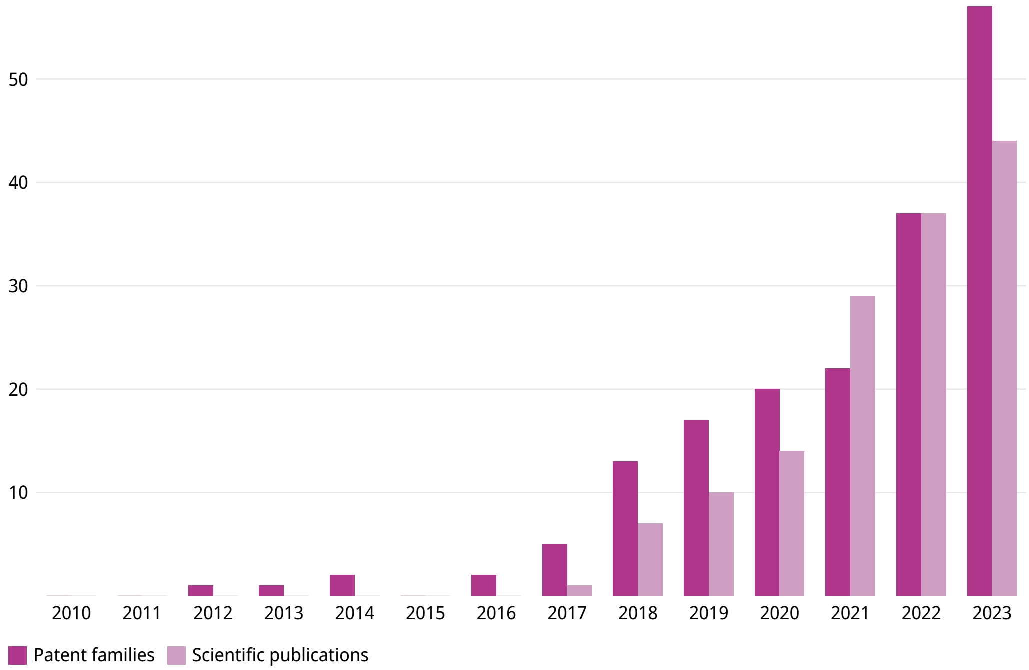
Blockchain implementations in satellite communication include using satellites as nodes within a blockchain network, as validators or miners, and for requesting that specific data transactions be stored on the blockchain. The benefits of integrating blockchain in satellite communication include enhanced security, improved efficiency, transparency, traceability and reliability. However, challenges, such as limited computational power, storage capacity, energy resources, latency issues, scalability and integration into existing systems must be addressed.

The analysis of scientific publications in the field of blockchain in satellite communication underscores a dynamic and rapidly evolving field, marked by intense research activity followed by signs of stabilization or a shift in focus. The global distribution of research output highlights not only the technological ambitions of leading nations, but also the strategic importance of blockchain technology in securing satellite communications on a worldwide scale. This global perspective is crucial for identifying potential areas for international collaboration and understanding the geopolitical dynamics within technological development.

Figure 5.8 shows the annual scientific publication trends from 2010 to 2023, revealing a significant growth in research and publications. This trend suggests an initial period of heightened interest and activity in the field, likely driven by an increasing recognition of blockchain's potential to enhance the security and efficiency of satellite communications. The sharp increase in publications reflects ongoing development and exploration within the field, indicating a robust phase of innovation and theoretical exploration. That said, patenting activity in the field of blockchain in satellite communications has only started to increase noticeably since 2017. In 2023, the number of published patent families in the field reached 57.

Research and patenting activities in blockchain technology for satellite communication started relatively late compared to other emerging technologies, with significant momentum building only since 2017

Figure 5.8 Development of global scientific publications and patents in blockchain in satellite communications, 2010–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Technology at a glance

Already in the early years of blockchain technology Lockheed has invented a system for managing data storage on a satellite platform using blockchain technology (EP3766190A1). The core idea involves a network of satellites working together to maintain a blockchain ledger. When a first satellite identifies a request for a ledger entry in the blockchain, it distributes this entry to other satellites in the network, which act as full nodes for the blockchain. The receiving satellites verify the ledger entry and, if verified, they enter the ledger entry into their individual ledgers. If the entry is not verified, it is not recorded. This decentralized system assures that multiple satellites participate in maintaining and verifying the blockchain, enhancing data integrity and reliability.

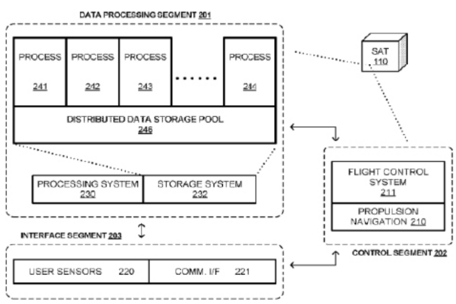


FIGURE 2

Source: EP3766190A1

Additionally, the blockchain can be part of a distributed application running on multiple satellites, processing requests from ground systems, sensors or other satellites. This Lockheed patent leverages blockchain technology so as to enhance the reliability and integrity of data storage and management across a network of satellites.

6 Glimpse into the future of transportation

In this chapter a synthesis of the main findings of the analysis in this report is provided based on the prevailing innovation dynamics. Challenges and opportunities for the transportation sector are discussed along with considerations for its different stakeholders. The road ahead to 2030 from a technology and innovation perspective is explored, and short stories for the future in 2050 and beyond are envisaged.

The transportation sector is at the forefront of technological transformation, driven by the dual megatrends of Sustainability and Digitalization. These are together reshaping how transportation systems operate across the four principal transport modalities – Land, Sea, Air, and Space. By analyzing patent data and other data sources like scientific research, market reports and governmental strategies, we have identified the key technology trends that align with the two megatrends. These technology trends can be categorized into four primary clusters: Sustainable Propulsion, Automation and Circularity, Communication and Security, and Human–Machine Interface. In this chapter a synthesis of the main findings of the analysis is provided, based on the prevailing innovation dynamics, to envision the future of transportation technologies.

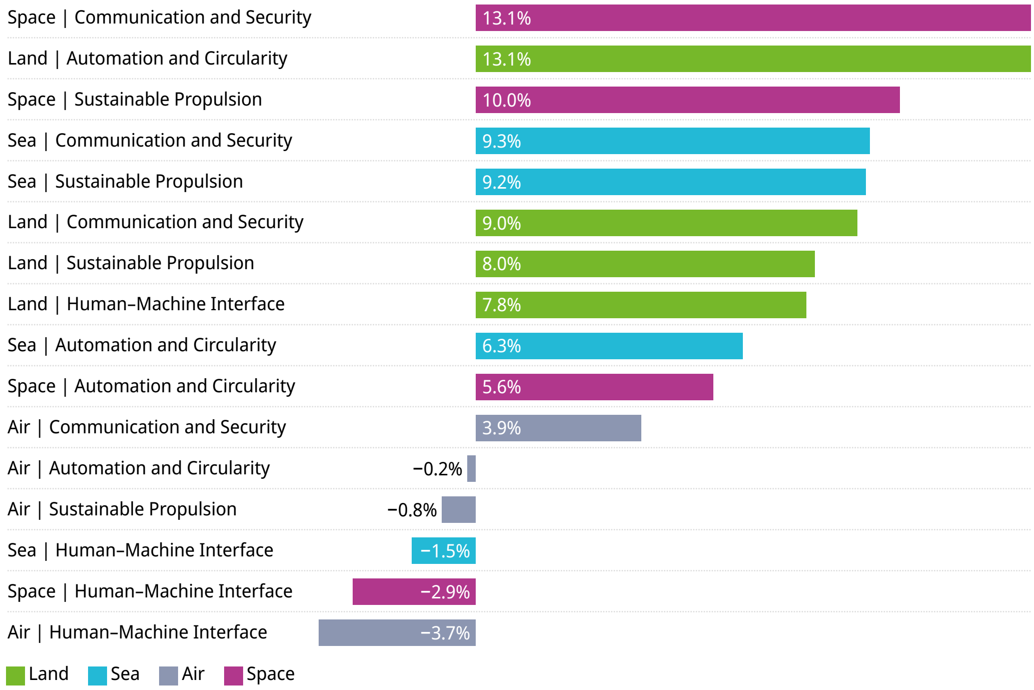
Synthesis of the report

Sustainability focuses on reducing the environmental impact of transportation through innovations in propulsion systems, material use, and circular economy practices. This includes the adoption of electric propulsion, hydrogen, and the recycling of critical materials. Meanwhile, Digitalization in transportation is primarily centered around enhancing connectivity, improving user interfaces, and automating processes. This includes the development of advanced communication networks, IoT integrations, and autonomous systems that rely on real-time data exchange and machine learning.

By categorizing these technologies, we identified the most impactful trends for each modality, based on the patent growth rate from 2018 to 2023 (Figure 6.1).

Recent patent growth is strong across many of the transport modality-technology trend groupings, but innovative activity in Air transportation has slowed in recent years

Figure 6.1 Innovation dynamics based on patent growth rate (CAGR), 2018–2023



Source: WIPO, based on data from EconSight/IFI Claims and Scopus, October 2024.

Communication and Security is a critical area of innovation across all transportation modalities, with varying degrees of growth. The highest growth is observed in **Space | Communication and Security**, with a 13.1% increase in patent activity from 2018–2023. This reflects a high demand for advanced communication technologies in space, driven by an increasing number of satellite launches, space exploration missions, and the commercialization of space travel.

Sea | Communication and Security follows closely, with a 9.3% growth rate. The maritime sector is increasingly adopting advanced Communication and Security technologies to improve navigation, monitor environmental conditions and enhance safety at sea. These advancements are essential as global trade via sea continues to grow and as maritime operations become more automated.

Land | Communication and Security has a 9.0% growth rate, indicating steady innovation in areas such as connected cars (V2X), smart city infrastructure and advanced traffic management systems. These technologies are crucial for developing smart transportation systems that are safer, more efficient and better integrated into urban environments.

In contrast, **Air | Communication and Security** shows a relatively low growth rate of 3.9%. This could suggest that, while there is ongoing innovation, the Air transportation sector may be more focused on other pressing challenges or that key Communication and Security technologies have already reached a certain level of maturity.

Automation and Circularity is another significant trend, with **Land | Automation and Circularity** leading the way at a 13.1% growth rate. This reflects the rapid development of smart manufacturing practices, and the increasing emphasis on Sustainability through circular economy principles. The Land transport sector, particularly automotive, is at the forefront of integrating automation into production and vehicle operation, while also exploring ways to recycle and reuse materials efficiently.

Sea | Automation and Circularity shows a 6.3% growth rate, highlighting the maritime industry's efforts to automate operations and embrace sustainable practices. This includes the development of autonomous ships and smart ports.

Space | Automation and Circularity has a similar growth rate, at 5.6%. In contrast, **Air | Automation and Circularity** has a negative growth rate of –0.2% over the period. While space missions are increasingly automated, and there is a growing focus on sustainable space exploration (e.g., minimizing space debris through international regulations), the relatively lower growth rate suggests that these areas are either facing more complex challenges or are at an earlier stage of development. The decline in Automation and Circularity technologies in Air transportation might indicate that the aviation industry is currently focusing on other areas.

Sustainable Propulsion is a high-growth area, particularly within Space and Sea modalities. **Space | Sustainable Propulsion** shows a 10.0% growth rate, driven by the need for more efficient and environmentally-friendly propulsion systems for space exploration and satellite deployment. This includes advancements in electric propulsion, solar sails and other innovative technologies that could reduce dependency on traditional chemical rockets.

Sea | Sustainable Propulsion follows, a 9.2% growth rate reflecting the maritime sector's shift toward reducing emissions through using alternative fuels like liquefied natural gas (LNG), hydrogen and battery-electric propulsion systems. The global focus on decarbonizing shipping is likely to be driving this trend.

Land | Sustainable Propulsion has a growth rate of 8.0%, which, while significant, indicates a more mature field having established technologies like EVs and hybrid systems. The ongoing innovation in battery technology and charging infrastructure continues to move this sector forward.

Interestingly, **Air | Sustainable Propulsion** shows a slight decline of –0.8%, suggesting that, while have been efforts to develop greener aviation technologies, such as electric or hydrogen-powered aircraft, the sector faces substantial technical and regulatory challenges that are slowing the pace of innovation. The challenges faced by the aviation industry in recent years, in particular those due to the effects of the COVID-19 pandemic, are also likely to have contributed to the recent slowdown in patenting activity.

HMI is experiencing varied innovation dynamics across different modalities. **Land | HMI** shows a growth of 7.8%, reflecting continued improvements in vehicle interfaces, such as touchscreens, voice control and augmented reality (AR) systems, which enhance the driving experience and safety.

However, **Sea | HMI** and **Space | HMI** have experienced negative growth rates of – 1.5% and –2.9%, respectively. This could indicate a shift in focus away from interface innovations in these modalities, possibly because existing HMI technologies have already reached a sufficient level of development, or because other areas, like automation and propulsion, are taking priority.

The most significant decline is seen in **Air | HMI,** with a –3.7% negative growth rate. This decline might be due to the aviation industry's current focus on other critical challenges, such as Sustainable Propulsion, and the post-COVID-19 challenges that the aviation industry has faced, as mentioned above.

The innovation dynamics across these four technology trends indicate a robust focus on Communication and Security and Automation and Circularity technologies, particularly within the Space and Land modalities. Sustainable Propulsion is also gaining momentum, especially within the Space and Sea sectors, driven by a global push toward reducing environmental impact. In contrast, HMI technologies appear to be either plateauing or declining within certain modalities, suggesting that other technology trends might be taking precedence as the industry shifts its focus to emerging challenges and opportunities.

Roy Amara

Roy Amara (1925–2007) was an American scientist, futurist and President of the Institute of the Future. He famously coined the following adage, that was to become Amara's Law: "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run."

This concept highlights how excitement over a new technology often leads to inflated expectations about how soon and significantly it will transform our lives. Over time, as early hurdles are encountered and initial predictions prove too optimistic, society becomes disillusioned. Yet, in the long term, these technologies can still achieve a profound and lasting impact – but just not as quickly as initially thought.

In the context of this report, autonomous vehicles provide a clear example of Amara's Law. Around a decade ago [1], many believed fully self-driving cars would be a common sight on the roads by now, transforming urban landscapes, reducing traffic accidents, and eliminating the need for personal car ownership. Major companies, including Google (Waymo), Uber and Tesla, projected ambitious timelines for autonomous cars. However, the technology has proven far more complex than expected, with significant technical, regulatory and ethical hurdles to be overcome.

As of 2025, autonomous vehicles still struggle in complex or unpredictable environments, such as incrowded urban areas or poor weather conditions. There have also been safety concerns raised, leading to regulatory roadblocks and increased scrutiny. Infrastructure and legal frameworks have not adapted quickly enough to support the widespread use of autonomous vehicles. [2]

Despite early optimism and many technological advances, fully driverless cars remain confined to controlled environments and limited testing areas, indicating a lengthy periodahead before they achieve the projected societal benefits on a wide scale. Nonetheless, in the long run, they might still revolutionize transportation once the hurdles are addressed. However, Amara's Law reminds us to temper expectations and approach predictions about rapid, radical change with caution.

Envisioning the future

As we look ahead to the year 2030, the transportation sector is set to become transformed by rapid advancements in technology, driven by the key trends identified in our analysis. The world of 2030 will be marked by interconnected, automated and sustainable transportation systems, with each modality of Land, Sea, Air, and Space contributing to a more efficient and environmentally-friendly global network.

High purchase price and slow turnover of personal cars is hampering EV rollout – Jason Schenker, Futurist

Record numbers of people began working from home in the wake of COVID-19, and those numbers are still very high. The increased amount of remote work is good for reducing commutes and is also good for reducing hydrocarbon consumption on the road and the associated emissions. However, we also see a record number of people engaging in e-commerce. This will make the utilization of low emission vehicles in delivery fleets important for reducing hydrocarbon emissions.

1 See, for example, PC Magazine (2013), 2013: The year of the autonomous car. Available at: https://uk.pcmag.com/cars/161/2013-the-year-of-the-autonomous-car.
2 See, for example, Brookings (2024), The evolving safety and policy challenges of self-driving cars. Available at: www.brookings.edu/articles/the-evolving-safety-and-policy-challenges-of-self-driving-cars.

Revolutions in transportation will take time because the average age of vehicles in the US fleet is at a record high of 14 years, according to the S&P Global Mobility Report. Moreover, due to high vehicle costs, the vehicle fleet age is likely to rise further. The implication for electric vehicles or any other innovation is clear: even if every new cars were to change to electric tomorrow, it would still take 14 years for every passenger car to be an electric car. The same would be true for automated self-driving vehicles.

Envisioning the year 2030, we combined the analysis of innovation dynamics with a technology maturity check (based on publicly available information) using the technology readiness level model adopted from NASA[3] to compose a picture of the future (Figure 6.2).

TRLs are a systematic framework that measures the maturity of a technology, from initial concept to full operational deployment

Figure 6.2 Technology Readiness Level (TRL) model adopted from NASA

Development phase	TRL	Indicators
Research concept	TRL 1	Basic principles observed and reported
	TRL 2	Technology concept and/or application formulated
	TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
Proof-of-concept	TRL 4	Basic validation of the technology in a laboratory environment
	TRL 5	Technology basic validation in a relevant environment
Minimum viable product (MVP)	TRL 6	Technology model or prototype demonstration in a relevant environment
	TRL 7	Technology prototype demonstration in an operational environment
Commercial product	TRL 8	Actual technology completed and qualified through test and first commercial system
	TRL 9	Fully commercial application and available for consumers

Source: WIPO/EconSight.

By 2030, the rapid innovation dynamics observed in Space | Communication and Security and Land | Automation and Circularity will have led to the deployment of a range of advanced products and systems that redefine how transportation operates.

Space | Communication and Security is set to revolutionize Space travel and satellite technologies. The concept of satellite constellations providing global internet coverage is already well advanced, with companies like SpaceX's Starlink and OneWeb in advanced stages of deployment (TRL 8–9).[4] By 2030, these constellations will likely be fully operational, providing not just global coverage but also high-speed, low-latency internet access to even the most remote areas. Cybersecurity measures to protect these networks are also being actively

3 NASA (2023). Technology readiness levels. Available at: www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels.
4 Shaengchart, Y. and T. Kraiwanit (2023). Starlink satellite project impact on the Internet provider service in emerging economies. Research in Globalization, 6, 100132.

developed and are likely to be robust by 2030 (TRL 7–9).[5] [6] Space tourism, while currently in its infancy with companies like Blue Origin and Virgin Galactic conducting suborbital flights, is expected to advance significantly, making orbital flights for civilians a feasible option by 2030 (TRL 6–7).[7] [8]

Progress in **Land | Automation and Circularity,** as well as **Land | Communication and Security**, will have revolutionized urban mobility by 2030. Autonomous vehicles (AVs) are currently being tested on public roads, with multiple companies targeting commercial deployment (TRL 7–8).[9] By 2030, we can expect AVs to be seen in urban areas, integrated with public transportation systems and operating within smart city frameworks. These vehicles will likely be produced in smart factories that utilize Industry 4.0 technologies, which are already being implemented (TRL 8– 9).[10] The circular economy in the automotive sector is also progressing, with advances in material recycling and sustainable design practices becoming industry standards (TRL 7–8).[11] [12] Thus, products such as fully autonomous electric vehicles and recyclable vehicle components are highly foreseeable by 2030.

In the maritime sector, **Sea | Communication and Security** and **Sea | Sustainable Propulsion** will have transformed shipping and naval operations. Autonomous cargo ships – already under development – are expected to see a limited deployment by 2030 (TRL 6–8).[13] [14] [15] At least some of these ships will likely use advanced propulsion technologies fueled by hydrogen derivates, currently in the prototype and testing phases for marine applications (TRL 6–7).[16] [17] Ports will likely become smart hubs, as the necessary AI and IoT technologies for logistics management are already commercially available and evolving (TRL 8–9).[18] [19]

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10 Mercedes-Benz (2024). Industry 4.0 and the networked factor. Mercedes-Benz Group. Available at: https://group.mercedes-benz.com/innovation/case/connectivity/industry-4-0.html.

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The sweet spot may be the growing market for vehicles in between bikes and cars – Tom Standage, The Economist

Cities are making multimodal transport easier. On the flip side, they're making car ownership harder. It's becoming more expensive and less convenient to own a car. I think having access to a vehicle or having access to transport is really what matters, not actually owning a car.

I also think that in the future we may have a wider mix of vehicle types. And the space worth watching is in between bicycles (or e-bikes) and cars (or electric cars). I'm thinking of things like electric quadricycles, such as the Citroën Ami, or cargo bikes. You wouldn't want to do a long road trip in them, but they are fine for short trips.

Challenges and opportunities

While 2030 holds the promise of significant advancements, the path forward is not without its challenges. Regulatory frameworks need to evolve rapidly to match the pace of innovation, particularly for automated vehicles and space travel. Existing regulations may need substantial adaptation to assure safety and foster innovation without stifling growth. The complexity of international cooperation, especially within the space and maritime domains, will require diplomatic efforts alongside technical advancements.

Funding remains a critical issue, particularly within capital-intensive sectors like space exploration and sustainable aviation. However, the rise of public–private partnerships, venture capital and innovative funding mechanisms, like green bonds, is already helping to drive technologies forward.

The convergence of sustainability efforts across different sectors presents a unique opportunity to reduce environmental impact while fostering innovation. New markets, particularly in urban air mobility and space, are likely to emerge as mature technologies creating economic growth opportunities.

AI integration across all modalities will continue to unlock new capabilities, making transportation systems smarter and more responsive. For example, generative AI (GenAI) is playing a key role in the development of autonomous driving, because GenAI models allow the simultaneous generation of multiple scenarios, the prediction of future vehicle trajectories and the advancement of decision-reasoning chains. These approaches enhance safety, efficiency and flexibility, while at the same time significantly reducing risk and associated costs.[20] GenAI can also optimize public transportation systems. By analyzing vast amounts of data on factors like population density, traffic patterns and passenger preferences, AI algorithms can devise more efficient routes and schedules for public transit networks.

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The future of transportation is mining and recycling! – Jason Schenker, Futurist

The future of transportation is a mix of software development, hardware development, and the integration of the two. It is about collecting data, testing, and the development of automation technologies. At the same time, it is also about fuel- efficient technologies, including electric vehicles. However, there is one really big catch when considering the future of electric vehicles: the limited supply of battery materials and their supply chains.

Battery materials for electric vehicles are relatively scarce. This means that battery material prices could rise dramatically if demand continues to rise but supplies remain constrained. As such, electric vehicles with low utilization rates are sub- optimal users of batteries compared to electric vehicles in fleets with high utilization rates. The utilization of individual personal lightweight vehicles, for example in the United States, might be in the 3–7% range. But almost all the time, those cars are sitting in a driveway or garage not doing anything. This is an inefficient use of battery materials.

Battery materials are much scarcer than oil. And some of them come from areas that are becoming more sensitive geopolitically. The most efficient allocation of these resources may require prioritizing the use of electric vehicles for fleets with high vehicle utilization operating at levels where the battery is not a major deterrent to operational optimization. Included among these vehicles would be mid-range medium-weight vehicles like delivery vans, mail trucks, buses, tugboats, and other vehicles that operate within a limited range and close to a depot where they can go for a recharge. Heavy long-haul trucks do not fit in this list because the weight of the batteries greatly reduces the range and thus the efficiency of their use in reducing hydrocarbon consumption.

Both heavy-duty trucks and personal vehicles embody sub-optimal electric vehicle deployment at scale globally given the current state of battery technology. On the upside, battery technology is evolving. However, even if batteries improve, critical battery raw materials coming from geopolitically sensitive places could hinder supply chain access and battery production potential for many countries. Hydrogen fuel-cell vehicles could be a great option. But we are not there yet, based on infrastructure and cost. Costs are falling, and the potential is rising, but it will take time. Looking to the future, I foresee a mix of transport solutions over time, both from an automation and software standpoint and from fuel use across different modes of transport.

The scarcity of battery materials and access to them is a big concern. There is going to be a massive shortfall of these materials through 2040. According to research produced by the International Energy Forum in conjunction with the Payne Institute of Public Policy at the Colorado School of Mines, we need 1.8 Chile’s worth of copper (Chile is the world’s biggest copper producer). The situation is similar for nickel and cobalt: we will need 1.3 Indonesia’s worth of nickel and 2.4 Democratic Republic of Congo’s worth of cobalt. Plus, this additional metal demand is only what’s required for the electrification goals of the energy transition through 2040.

If the future of transportation should remain centered on electric vehicles as the main conduit of the energy transition, then the future of transportation is mining. A lot more mining would be required for those materials that make up batteries: on land, on and under the seabed floor, and perhaps at some point on asteroids.

A personal electric car battery – the utilization rates of which may be around just 5% for personal vehicles – is far too valuable a resource to have sitting in a garage the vast majority of the time. Although consumer demand for electric vehicles has resulted in great technological innovation, if we don't find a better way to stretch these battery materials, we're going to have a major shortfall in battery production and significant spikes in battery prices. This means the other future of transportation is recycling batteries. The need to reclaim those scarce battery materials and make the entire cycle more sustainable is essential for making electric vehicles a lasting part of the energy transition.

Most companies, countries, and individuals are trying to reduce their carbon dioxide footprint. To that end, we need to stretch the use of hydrocarbon molecules in fossil fuels as well as the use of battery materials.

Developing hydrogen and other renewable fuels will be critical to reducing emissions as will generating more power to fuel electric and other low carbon footprint vehicles. Power grids will need to increasingly draw power from a range of sources, including sustainable sources like solar and wind, as well as nuclear. With automated vehicle potential increasing, the use of data and AI will rise, which also requires a lot of power. So, the future of transportation will also be about power generation, power plants, power storage (with large-scale batteries), and power grids. On the upside for electric vehicle batteries, once we get to self-driving cars, we would have the potential for personal vehicle fleets that would offer a higher utilization rate of electric batteries.

In any scenario, we will have to drastically increase mining, which will leave an environmental footprint. These things are not without an environmental trade-off. It will be very difficult to have everything green and clean and cheap and available and without any environmental impact. We will need to make trade-offs in transitioning to a world in which we have clean, cheap, green, affordable, and available transport for everyone. The process is going to require massive investment, major technological innovation, significant production efficiencies that lower costs, and a lot more time than most people expect.

When people look back at this transition a hundred years from now, they will see that the changes in transportation and the energy transition was a process. And, as with any process, it will take time.

Considerations for the future of transportation

As we approach 2030, the following stakeholders within the transportation sector might find it beneficial to explore the opportunities that emerging technologies present and consider ways to collaborate in order to foster innovation.

Governments and policymakers may want to consider continuing to nurture innovation through strategic investments in research and development and by fostering public-private partnerships. Creating flexible and adaptive regulatory environments could be a way of ensuring that new technologies are safely and effectively integrated into society, which in turn might pave the way for widespread adoption and public trust.

Additionally, governments play a vital role in standards development – a key area for the future of transportation. Developing and enforcing standards can create a cohesive framework for interoperability, safety and performance across various technologies and regions. Consistent standards will be essential for integrating complex systems like autonomous vehicles, electric infrastructure and digital connectivity. In a rapidly evolving technological landscape, aligning on standards early could simplify regulatory processes, reduce compliance burdens on industry and help harmonize innovations across borders.

By participating in international standards organizations and establishing a collaborative approach to standards, governments can support the global compatibility essential for cross-border transportation and trade. In turn, this could lead to a more unified and sustainable global transportation system, supporting economic growth and encouraging innovation that aligns with broader societal goals such as sustainability and accessibility.

Industry leaders and innovators could focus on areas with a significant growth potential such as automation and sustainability. There could also be value in exploring untapped opportunities in less dynamic sectors that might nonetheless yield substantial benefits. By integrating sustainable practices into their core strategies, companies could find themselves better aligned with evolving regulations and growing consumer demand for environmentally responsible solutions. Another essential consideration is collaboration on standards development. By working with governments and regulatory bodies early in the development cycle, industry leaders can help shape standards that benefit the sector as a whole, ensuring that innovations are interoperable, safe and compatible across global markets.

Emphasizing sustainable supply chains is another key avenue. As sustainability becomes a higher priority for consumers, investors and policymakers alike, companies that commit to decarbonizing their supply chains, minimizing waste and promoting a circular economy could find themselves better aligned with regulations and market expectations. This could involve using more sustainable materials, designing products for longevity and investing in the infrastructure needed for recycling and repurposing materials at scale.

Finally, building public trust in new technologies is crucial. Industry leaders can play an active role in education, transparency and communication efforts to address public concerns about new transportation solutions such as safety and data privacy. By prioritizing transparency and accountability, companies could help promote consumer confidence, supporting smoother transitions to new technologies and fostering long- term brand loyalty.

Researchers and academics might consider investigating the challenges that could hinder innovation, particularly with an emphasis on developing new materials and production methods that are environmentally sustainable, cost-effective and scalable. For example, research into lightweight materials, biodegradable components or renewable energy sources could support the decarbonization of the transportation sector. Advancements in battery technology, hydrogen fuel cells and energy storage will be essential to electrifying transportation systems and reducing reliance on fossil fuels. Additionally, breakthroughs in materials science could improve the lifespan and durability of vehicles and infrastructure, leading to reduced waste and resource usage over time.

With transportation moving toward interconnected systems, researchers can focus on models that integrate transportation technologies with urban infrastructure. Smart cities require the advanced modeling of traffic patterns, energy consumption and environmental impact. Researchers could work on simulations and data-driven models that predict how new transportation options will affect cities and help design infrastructure that supports efficient, safe and sustainable movement of people and goods. Research in this area might also include strategies for better public transportation systems, shared mobility options and micromobility solutions that reduce traffic congestion and emissions.

The challenges in transportation are complex and require expertise from multiple disciplines, including engineering, environmental science, data science, ethics and economics. International collaboration will be crucial, especially because transportation is increasingly a global system with cross-border standards and interoperability needs. Partnerships between universities, research institutions, governments and industry could accelerate innovation by pooling resources and knowledge. By collaborating globally, researchers can also address regional variations in transportation needs and adapt solutions to local contexts, thereby enhancing global mobility and accessibility.

We cannot manage traffic or infrastructure separately from managing the public transportation system; they have to be under one umbrella authority – Mohamed Mezghani, International Association of Public Transport (UITP)

The empty roads we saw during the COVID-19 pandemic were a stark reminder of how much space in our cities is dedicated to cars. It was wishful thinking that the pandemic would change things, as we now see that traffic congestion is back. And this is a global trend.

There is a risk to our cities that comes from time lost sitting in traffic, more pollution and an overall negative effect on the economy. We must provide an answer to people's need to travel and rethink the way our streets are shared between different modes of transport.

Electrification, also of city buses, is the first trend I foresee. It is not simply about replacing diesel with battery, but also about redesigning the depots, building relationships with power companies, and addressing supply chain challenges, when cities all over the world are clamoring for fleets of electric buses.

Digitalization is another related trend that can transform urban transportation. From more efficient operations to flexible, on-demand services and predictive maintenance, to better services for travelers. This comes with the challenge of cybersecurity, protecting the entire system, especially with the growing automation of vehicles. Here, I am very clear that we should not substitute individually-owned cars by individually-owned driverless cars. Because if we do that, we will make the challenge worse, because we will have empty cars running in our streets and this will create more traffic. Our approach should be to integrate on-demand and shared mobility within public transport.

Something not often highlighted is a shortage of staff within the public transportation sector in many regions of the world. This impacts not only the hiring of drivers, but also hiring people with the types of skills that electrification and digitalization will need. The problem is that we are competing with so many other sectors like banking or manufacturing for the same set of skills. Public transportation efforts should be proactive in finding such skilled people.

Added to that only about 20% of public transportation staff are women. But in many countries they are the dominant users of public transportation. Women comprise about 60% of users in France. We need to get more women involved: in managing, in designing, operating and maintaining. And maybe this is the right time for that.

These days, public transportation is also coming under scrutiny for not generating enough revenue. Cost is increasing while ridership is recovering. In addition, policymakers want low fare or even free public transport. So, we have this equation whereby costs are growing and revenues stagnating or decreasing. This means that the model needs to change.

Some ideas envisage generating revenue from other sources through making those who benefit from public transport pay for it. For instance, those real estate or landowners whose property values increase, because a metro is serving them; or those employers for whom public transport brings their staff to the workplace. In addition, service quality and options need to be good. This will help a cultural shift away from thinking that an individual car is the best option for getting around.

We cannot ask people to leave their car, if we don't offer an alternative that is high quality, affordable and which goes everywhere. This is possible only, if we have an integrated view of mobility. We cannot manage traffic or infrastructure separately from managing the public transportation system. We need to try to tackle all modes together and to put ourselves into the shoes of travelers. A person who uses their car one day could be a bike user the next, and also use the bus or take a taxi. It is complex. But it’s the only way to tackle it. And we cannot ignore the large, informal transport networks in many places around the world. They should be considered part of the public system, ultimately to the benefit of everyone.

Developing a robust public transport system can be done. The main challenge is having the political will to do it. Countries that have done so have not regretted it. Maybe there needs to be an opportunity, an incentive. For example, the FIFA World Cup brought the bus rapid transit system to Johannesburg in 2010, and the driverless metro to Doha in 2021, and with it the belief that doing so was good for the country.

The road ahead to 2030

The future of transportation lies at a complex intersection of Sustainability and Digitalization, where continuous innovation must navigate the challenge of advancing both these megatrends simultaneously. As we look toward 2030, it becomes increasingly clear that a holistic, integrated approach leveraging the unique strengths of each transportation modality will be essential in creating a more connected, efficient and sustainable global transportation network. Land, Sea, Air, and Space transport are not isolated systems but are interconnected elements of a broader ecosystem. Innovating collectively within this ecosystem can lead to transformative advancements that surpass the potential of any single modality.

Advancements in Space communication technologies, for instance, can significantly enhance global navigation and communication systems, benefiting both maritime and aviation industries. Similarly, breakthroughs in Sustainable Propulsion within the maritime sector can inspire innovations in Land transportation, particularly in heavy logistics and long-distance travel. Ensuring that innovation in one area informs and drives progress in others can build a transportation system greater than the sum of its parts.

However, it is crucial to recognize the substantial investment required to master both Sustainability and Digitalization, especially in a world where business environments are increasingly fragile owing to geopolitical tensions, protectionist policies and conflicts. These challenges add layers of complexity to achieving the dual goals of Sustainability and Digitalization, as the cost of innovation rises and the stability of global markets is questioned. As such, stakeholders may need to prioritize adaptability and resilience in their strategic planning, ensuring that investment is robust enough to withstand these external pressures.

The next decade promises to be one of profound change for transportation technologies, driven by the technology trends identified in this report. As Sustainability becomes ever more critical and Digitalization deepens, the transportation sector will need to adopt strategies that are flexible and responsive to the rapidly changing technological landscape.

To navigate these challenges, stakeholders across the industry – governments, businesses, and researchers – might want to consider embracing proactive and innovative approaches. This involves not only developing new technologies but also rethinking regulatory frameworks, business models and research priorities. Given the heightened risks associated with global economic and political instability, a concerted effort to anticipate future needs and to create solutions that are not just reactive but transformative will be essential.

As we journey toward 2030, the transportation sector has the opportunity to redefine mobility in a way that is more sustainable, efficient, and inclusive.

Despite recent challenges [21], Mobility as a Service (MaaS) will gain more popularity because it offers a seamless, flexible, and user-centric approach to transportation. By integrating various modes of transit – like buses, trains, ride-hailing, bike-sharing, and even car rentals – into a single digital platform, MaaS allows people to plan, book, and pay for journeys in one place via an app on their smartphone. This convenience is especially appealing in urban areas, where managing multiple apps, schedules, and payment systems can be a hassle.

MaaS also supports a shift toward more sustainable and shared transportation. It encourages people to combine public transit and shared mobility options instead of relying solely on private cars, which helps reduce traffic congestion, lower emissions, and optimize urban space. It also offers cost efficiency through tailored subscription models or pay-as-you-go plans, making transportation more accessible and affordable for a wide range of users.

MaaS apps can integrate innovations across all modalities, and by remaining vigilant against the challenges posed by global uncertainties, we can ensure that the transportation systems of the future are equipped to meet the demands of a rapidly evolving world, paving the way for a truly connected and sustainable global community.

21 See, for example, ZAG Daily (2024), MaaS Global is dead: Long live MaaS. Available at: https://zagdaily.com/trends/maas-global-is-dead-long-live-maas.

Goodbye traffic jams, hello green commutes: the future is closer than you think – Martin Ettlinger, Verkehrshaus (Swiss Museum of Transport)

By 2050, I believe that mobility will be defined by a complete transformation toward environmentally-friendly, decarbonized transportation solutions. The foundation for this development was laid long ago, with pioneers like the Swiss Tribelhorn company, which was already manufacturing electric vehicles as early as the 1900s, long before the electric mobility boom. These early visionaries are now not only role models, but also trailblazers for the transportation of the future.

I envisage the cities of 2050 as smart, interconnected hubs with a completely new flow of traffic. Public transportation will be fully electric and autonomous. High-speed trains will connect metropolitan areas, while covered, climate-controlled networks of hyperloop-like systems will link cities in just minutes. These transport modes will be nearly silent and extremely energy efficient. In urban areas, traffic jams and air pollution will be a thing of the past, as private cars will have almost completely disappeared from the streets.

Electric vehicles will dominate not only public transport, but also the private sector. Vehicle fleets, in the form of car-sharing services, will be the norm. Cars, trucks and delivery vehicles will be autonomous electric vehicles that communicate with one another to optimize traffic flow and ensure safety. These vehicles will be intelligently controlled by infrastructure, allowing them to communicate with the power grid and feed energy back when needed – a concept of bidirectional charging stations.

Aviation will also take a significant step forward: airplanes will now be electric or be powered by synthetic jet fuel derived from green hydrogen. This will allow for sustainable long-distance travel. Drones and flying taxis will complement urban transport by covering short distances swiftly and emissions-free, operating quietly and unobtrusively within cities.

Additionally, innovative solutions for freight transportation will be developed. E-cargo planes and autonomous freight vehicles will rely on the green power grid to transport goods efficiently and emissions-free. The entire supply chain will be interconnected to ensure minimal energy consumption and maximum flexibility.

Therefore, the Swiss Museum of Transport in Lucerne addresses in its new exhibition the following vision: By 2050, expect all transportation modes to be interconnected, creating a global, sustainable network that not only reduces CO_2 emissions, but also improves the quality of life for people. The pioneering spirit of the past will live on, shaping a future where mobility and transportation are efficient, sustainable and intelligent.

Beyond 2030: yesterday's dreams, today's realities

When we think about the future, it is easy to imagine a world shaped by advancements in technology, shifts in culture and unexpected challenges. But how do we envision futures that are not only possible but also desirable? This is where normative scenarios come into play. Unlike speculative or exploratory scenarios, which explore a range of possible futures, normative scenarios focus on desired futures – outcomes that align with certain values, goals or societal visions. By creating normative scenarios, we can better understand what steps are needed to guide today's choices toward a future that reflects our best aspirations.

To bring this concept to life and to conclude this WIPO Technology Trends report on the Future of Transportation, we will explore three short stories. Each story is a piece of design fiction depicting a unique normative scenario[22] in different areas of life and the role that technological innovation will need to play if these futures are to be achieved:

22 Harvard Business Review (1985). Scenarios: Uncharted waters ahead. Available at: https://hbr.org/1985/09/scenarios-uncharted-waters-ahead.

- **Urban cityscape "Dreams in the skyline"** – imagine a future sustainable city where autonomous vehicles, green spaces and clean energy have transformed urban life. In this future, smart transportation systems make cities livable, eco-friendly and deeply interconnected (Figure 6.3).
- **Autonomous smart ports "The changing tides"** – picture a fully-automated, green port that operates without human intervention, seamlessly balancing efficient global trade with environmental stewardship (Figure 6.4).
- **Seamless hypersonic air travel "From layovers to liftoff"** – envision a world where hypersonic, environmentally-friendly travel connects families across continents, making international air travel easy, enjoyable and sustainable (Figure 6.5).

Each story highlights a unique use case, illustrating how technology, values and thoughtful planning could shape a future aligned with societal goals for sustainability, connectivity and well-being.

Future scenario: “Dreams in the skyline”

Figure 6.3 Urban cityscape

As they stood together on the path, the hum of a distant drone filled the air, blending with the leaves rustling in the breeze. Emma pointed toward the cityscape towering in the distance, her finger tracing the sleek lines of a flying taxi as it glided past the illuminated skyscrapers.

“Grandpa, look! Is that what you were telling me about?” she asked excitedly.

Grandpa Jack’s eyes followed the direction of her gaze. “Yes, that’s one of them alright. Those flying cars were once a distant dream, when I was young like you; something you’d see in movies or read about in science fiction books. I remember when companies were just starting to test them. They didn’t look nearly as elegant as they do now. And people weren’t sure if they’d ever be safe enough to use.”

He motioned toward the self-driving car parked beside them, its wheels glowing softly as though waiting patiently for their next command. “Back in 2025, most cars still needed a driver. And even the self-driving ones weren’t completely autonomous.

They had a hard time handling busy city traffic or unusual weather. Now, these cars navigate better than we ever could have done ourselves.”

Emma looked back at her grandfather, her face a mix of curiosity and admiration. “And the city? Did it always look this way?”

He shook his head. “No, not at all. It was just beginning to change back then. The idea of sustainable urban areas was popular, but most cities were still full of congested streets and old infrastructure. The push for greener spaces and energy- efficient buildings was there, but it was slow going, like me!”

He sighed, then added, “It’s amazing how much has changed in just a few, short decades. We dreamed of a future back then where technology could make life better without harming the planet. Standing here today, seeing you grow up in a world where those dreams are a reality… it makes me feel like we did something right.”

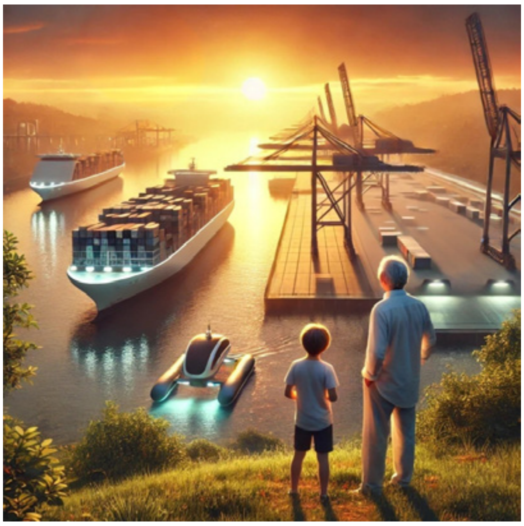
Emma gave his hand a little squeeze. “You did right, Grandpa. You helped imagine this world. And now, I get to live in it!”

As they continued to watch the city breathe life – flying taxis zipping across the skyline, drones delivering packages, while people at leisure strolled through lush parks that seemed as though woven into the urban fabric – Grandpa Jack couldn’t help but feel a sense of pride and hope. The world that he could once only imagine was now there in front of him, and he smiled at the thought that Emma would grow up knowing that this was her world, and the only world she had ever known.

Source: Image generated using OpenAI.

Future scenario: "The changing tides"

Figure 6.4 Autonomous smart ports



The sun was setting as Grandpa Jun and his grandson Hàoyǔ stood by the river quietly watching the port below in motion. Ships glided into dock on their own, as cranes turned to greet them before seamlessly unloading neatly stacked containers in readiness to be collected by a fleet of automated guided vehicles and carried onward to their destination inland. There wasn't a human anywhere to be seen.

To Hàoyǔ, this was just how ports are.

Grandpa Jun, however, couldn't take his eyes off the scene. "Do you know, when I was young, ports were noisy places crowded with people. Ships ran on diesel, and we had to haul everything by hand," he said, shaking his head ruefully.

Hàoyǔ shrugged, while watching yet another ship dock itself perfectly. "Really? Why didn't they just use AI?," he asked disbelievingly.

Grandpa chuckled. "We didn't have that kind of smart technology just yet. Ships ran on fossil fuel, not solar or hydrogen. And they certainly didn't navigate themselves!"

Hàoyǔ pointed to a small drone skimming over the water. "What's it doing, Grandpa?," he asked, intrigued.

"That's a cleanup drone. It removes plastic and keeps the water clear. And if there's any pollution, it cleans that up too," Grandpa Jun explained. "Back then, ports didn't worry much about the ocean. They just focused on moving cargo."

Hàoyǔ nodded, watching as another drone zipped by overhead. "So, no one had electric trucks either?"

"Not like these," Grandpa said, watching the trucks move quietly between the containers.

"Everything was loud, smelly, and people had to drive the trucks themselves. But nowadays this port runs on renewable energy and practically takes care of itself."

Hàoyǔ looked at the port, unimpressed at what he had heard. "So, it was really different back then?"

Grandpa Jun smiled. "Aye. It was nothing like this – no AI, no eco-friendly ships, no cleanup drones. Watching this... it's like a dream come true."

Hàoyǔ just shrugged. "Well, it seems normal to me."

With a grin, Grandpa ruffled his grandson's hair. "It is, my dear Hàoyǔ. And that's what's so wonderful about it."

Source: Image generated using OpenAI.

Future scenario: "From layovers to liftoff"

Figure 6.5 Seamless hypersonic air travel

Anna and Leo were bouncing with excitement as they waited at the airport in Sydney. Their grandma was coming all the way from London. And thanks to the revolutionary hypersonic aircraft, she would be there in under two hours.

As soon as they saw the sleek, silver vehicle, they ran to greet her as she stepped out, each grabbing one of her hands.

"Grandma!" they shouted in unison: "How was your flight?"

Grandma laughed, hugging them both to her tightly. "Oh, it was incredible! You know, when I was younger, traveling halfway across the world was a completely different experience. It was never so quick and easy as it is now."

The three of them walked over to sit on a cozy bench in the terminal's quiet garden area, surrounded by greenery and soft, ambient lighting. Grandma looked around at the bright modern facility, with its futuristic design and serene atmosphere. "I can hardly believe it myself," she said, shaking her head.

Anna's eyes widened. "What was it like back then, Grandma?", she asked.

"Well," Grandma began, settling into her seat, "traveling from London to Sydney used to take more than 20 hours! We'd have to navigate huge, crowded airports and wait in endless security lines, and endure long-haul flights with cramped seats and noisy engines. It was exhausting and felt like an eternity."

Leo wrinkled his nose. "That sounds awful!"

Grandma chuckled. "It wasn't all bad. But it was certainly tiring. And it wasn't great for the planet either. Those planes burned so much fuel, creating a lot of pollution. Now, thanks to hypersonic air travel, the whole journey is incredibly fast and eco-friendly."

She glanced over at the sleek aircraft resting nearby, its gleaming surface reflecting the soft light of the terminal. "These hypersonic vehicles use advanced propulsion systems that rely on sustainable fuels, you know. They fly at high altitude, reaching speeds exceeding Mach 5 and offering stunning views of Earth's curvature, before descending gently to land at their destination."

Anna pointed at the hypersonic airplane in awe. "And it only takes two hours, right?"

"Exactly," Grandma said, her face lighting up. "I boarded in London, and before I had time to watch a whole in-flight movie, here I was in Sydney. No layovers and a breathtaking view of the planet along the way. It's like stepping into the future."

Leo grinned. "So that means you can visit us more often now?"

Grandma squeezed his hand. "Absolutely! I can come and see you whenever I like. These hypersonic flights have made the world feel so much smaller. Back in 2025, a trip like this was a grueling ordeal. But now, it's almost as easy as hopping on a train!"

Anna leaned against her grandma, beaming. "We're so happy you're here, Grandma."

Grandma smiled. “I am too, my loves. I never thought I’d see the day when I could travel from London to Sydney and feel like I’d barely left home. It’s amazing how much travel has changed for the better.”

Leaving the terminal together, Grandma couldn’t stop marveling at the incredible world her grandchildren were growing up into – a world where even traveling between cities so far apart as London and Sydney felt like nothing at all.

Source: Image generated using OpenAI.

Acronyms

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
AtJ	Alcohol-to-Jet
BEV	Battery Electric Vehicle
CAGR	Compound Annual Growth Rate
CCAM	Connected, Cooperative and Automated Mobility
CEO	Chief Executive Officer
CERN	European Laboratory for Particle Physics
C-ITS	Cooperative Intelligent Transport Systems
CO_2	Carbon Dioxide
CPC	Cooperative Patent Classification
DPA	Discrete Pareto Analysis
EASA	European Union Aviation Safety Agency
EDT	Emerging and Disruptive Technologies
EIT	European Institute of Innovation and Technology
EP	European Patent
EPC	European Patent Convention
EPO	European Patent Office
EU	European Union
EUIPO	European Union Intellectual Property Office
EV	Electric Vehicle
eVTOL	Electric Vertical Take-Off and Landing vehicle
FCEV	Fuel Cell Electric Vehicle
FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene
GenAI	Generative Artificial Intelligence
GII	Global Innovation Index
GPS	Global Positioning System
HEFA	Hydroprocessed Esters and Fatty Acids
HMI	Human–Machine Interface
IAM	Innovative Air Mobility
IAS	Innovative Aerial Services
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IMO	International Maritime Organization
INTA	International Trademark Association IP Intellectual Property
IoT	Internet of Things
IP	Intellectual Property
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
IPF	International Patent Family
IRENA	International Renewable Energy Agency
IS	International Standard
ISRU	In-situ Resource Utilization
ITS	Intelligent Transport System

LEV	Light Electric Vehicle
LNG	Liquified Natural Gas
MaaS	Mobility-as-a-Service
MR	Mixed Reality
MVP	Minimum Viable Product
NH_3	Ammonia
OECD	Organisation for Economic Cooperation and Development
OJEU	Official Journal of the European Union
PAS	Publicly Available Specification
PCT	Patent Cooperation Treaty
PtL	Power-to-liquid
R&D	Research and Development
RSI	Relative Specialization Index
SAF	Sustainable Aviation Fuel
SDG	Sustainable Development Goal
SSB	Solid-State Battery
TEU	Twenty-foot Equivalent Units
TR	Technical Report
TRL	Technology Readiness Level
TS	Technical Specification
TWh	Terawatt Hours
UAM	Urban Air Mobility
UM	Urban Mobility
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VCA	VTOL-Capable Aircraft
VR	Virtual Reality
VTOL	Vertical Take-Off and Landing
UIC	International Union of Railways
UITP	International Association of Public Transport
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Organization
XR	Extended Reality
ZEV	Zero-Emission Vehicle

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Appendix

A.1 Methodology for patent analysis

Patent identification and mapping to a definition

Transforming a technology definition into a patent data collection is a crucial step when underetaking patent analysis. The most relevant aspect is the method of finding patents that fit the definition. The approach used in this report followed established guidelines, such as those provided by WIPO,[1] to gather the patents to a definition within an optimal relation of precision and recall. More specifically, the approach encompassed extensive searching for keywords and relevant synonyms, scrutinizing patent classes, combining search terms, and excluding keywords that were irrelevant to the specific technology we were investigating. This methodical process enabled us to construct a foundation of structured information from the vast patent landscape. It was a crucial step in ensuring that our search was both thorough and targeted. However, certain emerging transport technologies, such as 'Urban Air Mobility' or 'Ammonia as a marine fuel', are modern concepts without clear technical definition and where patent classes are not fully established yet. Therefore, we used an alternative AI-powered approach for capturing relevant patents that fit the technology definitions in these emerging technologies.

Data collection, patent counting

- Simple patent families are counted as a proxy for individual inventions in the report. A simple patent family is a set of patents in various countries in relation to a single invention. The technical content covered is considered to be identical. All patent documents have the same priority date or combination of priority dates. The first publication by a member of a patent family counts as the publication year.
- Most analysis in the report refers to numbers of patent families. Only published patent families have been studied.
- Patent families generally include only patents and not utility models, without assessing their legal status.
- The origin of the inventor (inventor's location or residence) is used as a proxy for the source of innovations. For patents with multiple inventors, we count the different locations listed and count the location for multiple inventors of the same origin once.

Utility models have been excluded from the patent analysis in this report, because the regional differences and lower inventive threshold for utility models can affect the accuracy and relevance of the analysis.[2] Utility models are not available in every country or region, therefore their inclusion can create inconsistencies in global studies, such as this report, for which comparability across countries and between regions is essential. The requirements for obtaining a utility model are also less stringent than those for a patent and they often cover incremental improvements rather than significant innovations, so including them can dilute the focus on more substantial technological advancements.

1 WIPO (2015). Guidelines for Preparing Patent Landscape Reports. Available at: https://www.wipo.int/publications/en/details.jsp?id=3938=.
2 See, Utility models, available at: www.wipo.int/web/patents/topics/utility_models.

A.2 Patent indicators

Patent application

To obtain a patent, an application must be filed at the appropriate IP office with all the necessary documents and fees. The IP office will conduct an examination to decide whether to grant or reject the application. Patent applications are generally published 18 months after the earliest priority date of the application. Prior to that publication, the application remains confidential.

Patent classification

Patent classification is a system for examiners of IP offices or other people to code documents, such as published patent applications, according to the technical features of their content. The International Patent Classification (IPC) is agreed internationally. The European Patent Office (EPO) and United States Patent and Trademark Office (USPTO) launched a joint project to create the Cooperative Patent Classification (CPC) in order to harmonize the patent classifications systems between the two offices.

Patent applicant/owner

Patents are filed by an applicant, which can be an organization or a natural person. Applicants are not inventors, even if sometimes they are similar. The applicant is in most jurisdictions and in most cases published with the patent and remains always the applicant. The applicant is not automatically the owner of a patent at a given time, even if that is often the case. Patents can be transferred or sold, or the applicant itself can be sold as a company in a merger or takeover. Therefore the “owner” of a patent might change over time and is not always published. For proper analysis, to consolidate incorrect spelling and to include merger and acquisition information in the analysis, the report used the ultimate owner concept in the IFI Claims global patent database. The most probable entity was then named as owner.

Patent family

A patent family is a collection of patent applications covering the same or similar technical content and all sharing one or more priority documents. Families are used to count inventions and not several patents corresponding to the same subject matter and filed in different jurisdictions. There are several definitions of patent families, including simple and extended patent families, depending on the number of priority documents shared (ranging from one to all priority documents). Patent family members are the individual patents filed in those jurisdictions where a patent applicant is seeking patent protection (e.g., WIPO, EPO) and all publications in relation to these. In the present study, we counted simple patent families (using a representative patent family member for each patent family), unless otherwise specified.

Granted patent

Once examined by the IP office, an application becomes a granted patent or is rejected. If granted, the patent gives its owner a temporary right for a limited time period (normally 20 years) to prevent unauthorized use of the technology outlined in the patent. The procedure for granting patents varies widely between locations in according with national laws and international agreements. Note that in the same patent family, an application can be granted in one location and rejected in another.

Inventor country/location

The origin of the inventor (inventor’s location or residence) is used as a proxy for the source of innovation. For patents with multiple inventors, we counted the different locations listed and counted the location for multiple inventors of the same origin once. If no inventor address was available, the patent priority country/location was used as a proxy for the source of innovation.

Priority country/location

The first location in which a particular invention has a patent application filed, also known as the office of first filing.

Filing country/location

The filing country/location is the legal jurisdiction in which a member of a patent family filed a patent application to seek patent protection.

PCT (WO patent)

The Patent Cooperation Treaty (PCT) is an international patent law treaty concluded in 1970, administered by the World Intellectual Property Organization (WIPO), between more than 140 Paris Convention locations. The PCT makes it possible to seek patent protection for an invention simultaneously in each of a large number of locations by filing a single "international" patent application instead of filing several separate national or regional patent applications. The granting of patents remains under the control of the national or regional patent offices, which is referred to as the "national phase."

European patent (EP patent)

A European patent can be obtained for all the European Patent Convention (EPC) locations by filing a single application at the European Patent Office (EPO). European patents granted by the EPO have the same legal rights and are subject to the same conditions as national patents (granted by anational patent office). A granted European patent is a "bundle" of national patents that must be validated at the national patent office to be effective in member locations. The validation process could include submission of a translation of the specification, payment of fees and other formalities at the national patent office. Once a European patent is granted, competence is transferred to the national patent offices. Other regional patents or procedures also exist: the Eurasian patent (EA), ARIPO patent (AP) for English- speaking Africa and OAPI patent (OA) for French-speaking Africa.

International patent family

An international patent family is defined as a patent family that has been filed and published in two or more jurisdictions (sometimes also known as foreign-oriented patent families or extended patent families). This contrasts with a domestic-only patent family or a non-international patent family, which consists of a patent family filed in only a single jurisdiction (often known as a "singleton").

WIPO Patent Momentum Indicator

The WIPO Patent Momentum indicator assesses global patent activity across combinations of the four technology trends – Sustainable Propulsion, Automation and Circularity, Communication and Security, and Human–Machine Interface (HMI) – and the four principal transport modalities (Land, Sea, Air, and Space). This indicator highlights which trend-modality combinations have shown the strongest patent momentum over recent years, based on both activity levels and growth dynamics.

Calculation steps:

1. Patent activity level
   - Calculate the average annual number of patent families for each tech trend-modality combination from 2018 to 2023.
   - Normalize these values using a Z-score.

2. Patent activity dynamics
   - Determine the compound annual growth rate (CAGR) of patent families for each combination over the same period.
   - Normalize the growth rates using a Z-score.

3. Total Patent Momentum score
   – Combine the normalized scores from the activity level and dynamics to obtain a total score for each trend-modality combination.

Innovation Maturity Matrix

The Innovation Maturity Matrix[3] depicts innovation intensity against the relative recency of innovation for each transport modality-technology trend group, based on future of transportation patent applications filed worldwide.

Innovation intensity is measured by absolute number of published patent families (it is not limited solely to active patent families).

Recency measures quantitatively how recently patent applications were first filed for certain technologies. It is calculated by a weighted average of patent applications, whereby a higher weighting is given to inventions filed in more recent years. Relative recency refers to a normalized recency, where the recency of the overall future of transportation patent dataset is 1.

Recency formula:

$$\bar{R} = \frac{\sum_{i=1}^{n} (w_i \times i)}{n \times \sum_{i=1}^{n} w_i}$$

where i = 1 for the first year of the survey period, and i increases by 1 for every subsequent year in chronological order; n is the total number of years of the survey period; and wi is the number of patent applications filed in the year i.

The four-quadrant matrix helps identify the following:

- Emerging interest – areas with related patent families that have the most recent priority year, but are not yet large in volume. Such areas are emerging and gaining rapid industry traction.
- Current hot topics – research areas that are the current industry focus and have a high number of accumulated patent families.
- Mature sectors – areas with a high number of patent families, but which are no longer the current key focus, as most patent families were published in the relative past.
- Modest development – areas that are not of recent focus and have a small number of filings. These could already have arrived at the final stage of the technology cycle, that is, at the decline stage; or else be areas that have been explored for a (relatively) long period of time, but had not gained traction at the time of the patent analytics report.

Relative Specialization Index

The Relative Specialization Index (RSI) compares the published patenting activity in two or more locations within the same technology area. RSI is a measure of a location's share of patent families in a particular field of technology as a fraction of that location's share of patent families in all fields of technology. It accounts for the fact that some locations file more patent applications than others in all fields of technology.

In other words, RSI has the advantage of providing a comparison of two locations' patenting activity in a technology relative to those locations' overall patenting activity. The effect of this is to highlight locations that have a greater specialism inthe technology area studied than expected from their overall level of patenting, and which might otherwise appear further down in the top inventor location lists, often unnoticed. A positive RSI value indicates that a location

3 A methodology developed by IPOS International (https://iposinternational.com).

has a higher specialization in this field than would be expected, whilst a negative value indicates a lower specialization than expected for that location.

The Relative Specialization Index (RSI) is calculated as follows:

$$RSI = \frac{X-1}{X+1}$$

where X is given by,

$$X_{c,t} = \frac{\frac{n_{c,t}}{N_c}}{\frac{N_t}{N}}$$

and

$n_{c,t}$ is the number of published patent families in country c for technology t,
$N_c = \sum_t n_{c,t}$ is the number of published patent families in country c in all technologies,
$N_t = \sum_c n_{c,t}$ is the number of published patent families in technology t in all countries, and
$N = \sum_c \sum_t n_{c,t}$ is the number of published patent families in all technologies and all countries.

A.3 Patent searches

Full details of the patent search strategies used to define the technology areas analyzed in this report can be accessed and downloaded from the WIPO Technology Trends webpages.[4]

4 See, WIPO technology trends, available at: www.wipo.int/web/technology-trends

The transportation sector is evolving - transforming how we move, connect and explore the world around us. *WIPO Technology Trends: Future of Transportation* dives into these changes, showing the next wave of transportation innovation, making transport smarter, greener and more inclusive.

Based on patent data and scientific literature data complemented by business information, policy, regulation and standards data, the report looks at transportation technologies and trends across land, sea, air and space. It identifies four primary technology trend clusters: Sustainable Propulsion, Automation and Circularity, Communication and Security, and Human-Machine Interface technologies.

In a world where sustainability and digitalization are driving forces, understanding the future of transportation is more critical than ever. This report aims to inspire action to drive the development of sustainable, efficient and connected transportation systems that benefit the entire world.

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