THE GLOBAL QUEST FOR SUSTAINABILITY

The Role of Green Infrastructure in a Post-Pandemic World

edited by **Carlo Secchi** and **Alessandro Gili**

with the knowledge partnership of

McKinsey & Company

ISPI

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The Global Quest for Sustainability.
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This study is an initiative of the ISPI's Centre on Infrastructure, promoted with the knowledge partnership of McKinsey & Company.

The Centre on Infrastructure focuses on how geopolitical and economic trends shape and are shaped by investment decisions on infrastructural projects. It aims to analyse global trends (new technologies, mobility, sustainability, etc.) and monitor major projects, also with a view to gauging their complementarity/competition and financing channels. Specific attention is devoted to the role of key economic and political players at all levels – from local to global – including regional and international development banks, whose "political" agenda is often crucial to foster public and private investment.

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Introduction

In the aftermath of the pandemic, global demand for infrastructure not only appears unfazed but has actually increased. As recovery plans in countries around the world are demonstrating, infrastructure will provide the backbone for a resurgence in world economies badly hit by the pandemic-induced crisis. Recovery will be further underpinned by the two pillars of decarbonisation and digitalisation, in a way consistent with the need to tackle the crucial problems of the moment, and emphasis will be placed on the application of ESG principles to business activities and on solutions compatible with a circular economy. Green and sustainable infrastructure will furthermore be crucial to meeting the carbon neutrality targets that many countries are now viewing as national priorities. The EU, US and Japan have all committed to becoming carbon neutral by 2050 while China is aiming at 2060. This means that a huge amount of new investment must be devoted to decarbonisation policies, with sustainable infrastructures playing a prominent role. In the US, out of the US$2 trillion earmarked by the American Jobs Plan launched in April 2021, US$621 billion will be devoted to transport, US$111 to water and US$100 to digital infrastructure.[1] In Europe, out of the €750 billion Next Generation EU fund, at least 37% must be invested in green transition and 20% in digital infrastructure.

[1] White House, *Fact Sheet: The American Jobs Plan,* March 2021.

As the 2021 ITF Transport Outlook recognises,[2] total transport activity will more than double by 2050 compared to 2015 under the current trajectory. Passenger transport will increase 2.3-fold and freight transport will grow 2.6-fold. Current decarbonisation policies, however, are insufficient to guide passenger and freight transport on to a sustainable path, considering that CO_2 emissions from transport will increase by 16% by 2050 even if today's transport decarbonisation commitments are fully implemented. However, if more ambitious decarbonisation policies are put in place (as many countries are doing through carbon neutrality plans), transport and freight CO_2 emissions could be reduced by about 70% by 2050 compared to 2015. A massive plan of investment is therefore essential.

Public resources are insufficient to cope with the huge global infrastructure gap, which the G20 Global Infrastructure Hub estimates at around US$640 billion yearly until 2040. In advanced economies, in particular, ageing infrastructure requires urgent new funds to ensure security, climate resiliency and upgrading. Private investors must therefore be called in to share the burden and take a leading role in green infrastructure investments. Unfortunately, in recent years, private investments in infrastructure have progressively decreased, falling to US$100 billion globally in 2019,[3] and to an all-time low of US$45 billion in emerging economies in 2020.[4] Urgent action is therefore needed to foster greater involvement of the private sector in green investment financing.

The first part of this Report focuses on analysing the main trends that will shape and challenge green infrastructure investments in the years to come. Quality infrastructure investments are crucial to ensuring sustainable and steady development and employment, reducing greenhouse gas

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[2] See International Transport Forum, *ITF Transport Outlook 2021*, June 2021.

[3] Global Infrastructure Hub, *Infrastructure Monitor 2020 Report*, October 2020.

[4] World Bank, Private Participation in Infrastructure (PPI) Global Report 2020, May 2020.

emissions, and meeting the UN Sustainable Development Goals and the objectives of the G20 Quality Infrastructure Investment (QII) endorsed at the 2019 G20 Summit in Osaka. What is still missing is a clear definition of what exactly sustainable and quality infrastructure is, based on internationally shared quantitative and qualitative criteria, including agreed KPIs (Key Performance Indicators). The European Union is moving in this direction by introducing the first EU Taxonomy. This offers clear advantages because it establishes a standardised and objective way of determining whether an asset contributes to sustainability and decarbonisation goals, and because it boosts the establishment of sustainable infrastructure as an asset class. A similar proposal for a specific social taxonomy will follow shortly. Progress will be further reinforced by the allocation of public funds, and by the application of so-called DNSH (do no significant harm) principles to ensure that projects do not conflict with the Six Environmental Objectives identified.[5] On 6 July, the European Commission adopted a package aimed at making private investments in the EU's green transition easier, more transparent and effective. The package consists of three major parts: a new Sustainable Finance Strategy, a European Green Bond Standard proposal and a Delegated Act (supplementing article 8 of the Taxonomy Regulation) on the information companies have to disclose about how sustainable their activities are.[6]

These steps are crucial to attracting more private funding, since they give private investors a clearer overview of green infrastructure bankable projects and bridge the gap between national planning priorities and private investors' needs. Furthermore, new forms of public-private cooperation such

[5] The Six Enviromental Objectives are: climate change mitigation, climate change adaption, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, protection and restoration of biodiversity and ecosystems.

[6] See European Commission, "Strategy for financing the transition to a sustainable economy", 6 July 2021.

as Public Private Partnerships (PPPs) and blended private and public resources will be of the utmost importance in reducing the perceived risk associated with infrastructure investments by private investors. Within this framework, a key role will be played by transition finance and green bonds, debt instruments that are fundamental to catalysing new private investments and redirecting capital towards low carbon assets.

The second part of the Report dealing with trends analyses major developments in the energy landscape. In particular, it highlights the global potential and impact of renewables in terms of investments and increased distribution grid flexibility. Among renewables, green hydrogen is the new hope for rapidly decarbonising electricity, industry and transport and for meeting the ambitious carbon neutrality targets set by several countries. It will play a particularly crucial role in sustainable mobility since the air and maritime transport sectors are extremely difficult to electrify. However, green hydrogen still has its shortcomings, such as the large quantities of renewables needed for its production and challenges concerning distribution infrastructure. In the transition towards a carbon neutral society and economy, a prominent role could still be played by natural gas too, which now represents 22.6% of global primary consumption. In air and maritime transport in particular, natural gas will be fundamental to boosting decarbonisation efforts and replacing heavily polluting fuels.

A chapter is also devoted to the decarbonisation of the logistic sector, whose activities account for around 12% of global GDP and a similar proportion of energy-related CO_2 emissions. There is general recognition that the decarbonisation of logistics will prove difficult, partly because the movement of goods is almost entirely powered by fossil fuel and also because the demand for freight transport is forecast to rise steeply over the next few decades. Potential solutions for decarbonising the sector will be presented, most of them of a mutually reinforcing nature.

Another crucial field for green infrastructure is the deployment of electric vehicles. Electric vehicle costs have plummeted over the past decade and are forecast to continue falling rapidly. This opens up a promising path towards decarbonised transport. Electric vehicle development is nevertheless facing various critical issues, including uncertain technology costs, consumer acceptance, and significant infrastructure investments. A chapter is therefore devoted to reviewing the state of the electric vehicle market, economic motivations for electric vehicle policy, the classes of policies used to promote electric vehicles, and the environmental effects of electric vehicles now and into the future.

New technologies can be a formidable ally in achieving carbon neutrality targets: they enhance the environmental sustainability of transport infrastructure by implementing innovative solutions in rail, airport, road, and port spaces. Digital solutions can create new modes of mobility – such as shared mobility – and update existing infrastructure and services. This results in enhanced efficiency for the overall infrastructure system and reduces traffic, pollution, greenhouse gas emissions, and travel time.

Sustainable transition would not be possible without serious commitment by the world's most industrialised countries. Between 2019 and 2021, the European Union, China, Japan, the United States and other countries announced bold measures to cut greenhouse gas emissions and ultimately become carbon neutral. Manufacturing, consumption and mobility will therefore change radically over the next few decades. The second part of this Report analyses the carbon neutrality and green infrastructure plans announced by the European Union, the United States, China and Japan, and highlights their similarities and differences. It is of the utmost importance that such plans be coordinated at an international level, to ensure that countries shift their industrial and social systems in the same direction. Otherwise, it will become difficult to achieve the international targets endorsed at the 2015 Paris Summit, and we shall see widening gaps between different international environmental standards. Last but not least, the application of different environmental standards and regulations could turn into a new race to the bottom in an attempt to gain competitive advantages, especially for emerging economies. However, the overall outlook is positive: many countries agree that a level playing field is no longer deferrable when it comes to environmental neutrality targets and standards, and this could present a formidable opportunity for a sustainable recovery from the pandemic, with new sustainable investments in infrastructure, new green industries and increased employment.

The infrastructure landscape, highlighted by country focuses in the second part of the Report, presents mainly geopolitical challenges. Over the last decade, starting from the launch of the Belt and Road Initiative (BRI) in 2013, infrastructure has become a key pillar in geopolitical competition. Now it is the turn of green and sustainable infrastructure. As an attempt to counter the Chinese BRI, the G7 leaders, gathered in Cornwall in June 2021, endorsed a declaration that envisages a new infrastructure plan shared by G7 countries: the Build Back Better World (B3W). Finance for this plan remains unclear and will have to be fine-tuned by a G7 Task Force, though the leaders announced investments worth hundreds of billions. The plan is designed to offer middle and low-income countries a high quality, sustainable and green alternative to the BRI. However, the most appropriate forum to find shared solutions to infrastructure competition is probably the G20, where the main emerging economies are represented. As recognised by the G20 Principles for Quality Infrastructure Investment endorsed at the G20 Summit in Osaka, quality investment in infrastructure will be crucial to ensuring a sustainable transition. Coordination will also be key to avoiding overlaps between the connectivity plans of different countries and consequent waste of public and private funds. One thing is certain: an agreed international focus on infrastructure, including a level playing field for all interested parties, is no longer deferrable if we are to overcome the challenges that lie ahead.

PART I
TRENDS

1. Private Financing for Sustainable and Quality Infrastructure in the Face of Covid-19

Naoyuki Yoshino, Nella Sri Hendriyetty, Derek Hondo

Infrastructure Needs to Achieve the SDGs

As societies continue to work towards achieving the Sustainable Development Goals (SDGs), many challenges exist in determining the most effective approaches to support them in doing so. One of the biggest lies the upgrading of current infrastructure, and the development and maintenance of new infrastructure, which is crucially important to promote socioeconomic development. Infrastructure is instrumental in increasing resilience economically, environmentally, and socially. It must be resilient itself so that it can withstand any shocks and stresses that it may encounter. Subsequently, infrastructure will contribute to increased productivity, promotion of financial inclusion, facilitate trade and connectivity, all while stimulating economic growth in a sustainable way if the appropriate planning and policies are implemented. This chapter emphasises the importance in investing in quality infrastructure and how this can support a transition towards more resilient and sustainable societies. It will highlight the spillover effects of infrastructure investments and how they can address many of the SDGs. Lastly, it will explore different innovative financing schemes which policymakers can adopt to alleviate the strain on public budget deficits, especially in the post-Covid-19 era.

Infrastructure can be categorised into two main types: soft infrastructure and hard infrastructure. Soft infrastructure refers to all the essential services that maintain economic, health, cultural, social standards, and the institutions which oversee these services within a society. Conversely, hard infrastructure covers the physical, such as roads, bridges, railways, and other built things. Digital infrastructure is not limited to one or the other and can also support the development of both soft and hard infrastructure. By investing in both types, including digital infrastructure, countries will be able to move closer towards achieving the SDGs.

Sustainable and Quality Infrastructure

Quality infrastructure can be defined as infrastructure that contributes in a significant way to the development of a region. This can be measured by evaluating the spillover effects of investment in a particular infrastructure project, which increases economic value of the region.

Once the infrastructure and affected areas or regions are identified, two approaches can be taken to determine whether the infrastructure is of high-quality and worthwhile to invest in. The first is to examine the changes in GDP in the area affected by or along the infrastructure, in the case of a road, railway, or water pipeline. The second approach is to observe the changes in tax revenue also in the area or region along the infrastructure. For both approaches, comparisons should be made between the situation with the built infrastructure and the situation without any infrastructure.

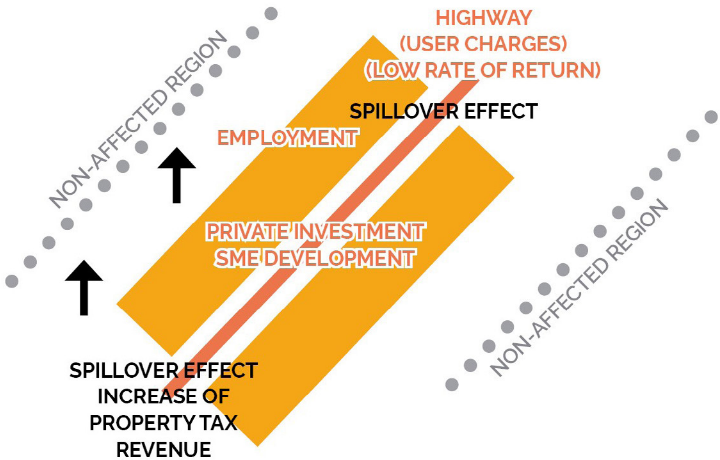
Quality infrastructure has a multiplier effect and brings immense benefits to a region. By investing in quality infrastructure, a region will see an increase in economic activities with the creation of new businesses and employment opportunities. Moreover, as businesses open and people move to the area, new residential districts will arise, leading to an increase in the revenue collected from property and corporate taxes (Figure 1.1).[1] To further increase the spillover effects generated by infrastructure investments, local policymakers and private companies need to work collaboratively to maintain the development momentum of a region, expanding beyond the initial infrastructure project.

One challenge that remains in both developing and developed countries is increasing connectivity between rural and urban areas. Both soft and hard infrastructure can play a role in connecting regions physically and digitally. Investing in infrastructure opens up opportunities to boost economic value, achieved through developing railways, roads, and highways. In the case of developing physical infrastructure, the agriculture industry, including farmers, will be able to transport their products to urban centres, increasing market accessibility and expanding trade networks to reach vast regions beyond their local areas. The following section will explore the potential spillover effects that soft and digital infrastructure investments can lead to.

Another important component of infrastructure is ensuring that it is sustainable. This means that policymakers, developers, and investors must establish long-term plans that incorporate the SDGs. Sustainable infrastructure needs to make cities better equipped with public transportation to increase social mobility and equity, increase access to healthcare and education, digital connectivity and technology, while also shifting to a greener, more efficient energy usage.

[1] N. Yoshino, U. Abidhadjaev, and N. Hendriyetty, "High-quality infrastructure and land acquisition for infrastructure development through land trusts", *Global Solutions Journal*, 2019, pp. 156-163.

Fig. 1.1 - Spillover effects created by infrastructure



Role of Digital Infrastructure during Covid-19 and Post-Pandemic Recovery

The Covid-19 pandemic, which has had widespread impacts on social and economic activity across the globe, has shed light on the central role that digital infrastructure and technology can play in society. With lockdowns in place, many businesses and education systems shifted their operations online. In order to do this, accessibility to stable internet connections through quality digital infrastructure became a necessity.

However, more than 4 billion people lack access to the Internet and of this figure, 90% are in developing countries.[2] This struggle with providing digital connectivity hampers the ability for information to be disseminated, which has consequences on business opportunities and education. Furthermore, failure

[2] United Nations Development Programme (UNDP), *Goal 9: Industry, innovation and infrastructure*, 2021.

to recognise the impacts that digital infrastructure can have on a region jeopardises not only business activity there but also secondary and university education. According to Yoshino and Abidhadjaev (2016),[3] investment in infrastructure that promotes education adds to the spillover effects (Table 1.1). Providing access to secondary education and training programs will better prepare the workforce with essential skills for entering labour markets. Higher education will enhance the quality of workers, an investment that will ultimately increase economic output. The level of education in a region is one of the determining factors of economic value, also contributing to the spillover effects of a given infrastructure project.

Tab. 1.1 - Positive effects of Education on Spillover Effects of Infrastructure

Dependent variable: log difference GDP per capita in 1991-2010			
Regression number	REG.1	REG.2	REG.3
Variables	Coef.	Coef.	Coef.
lnY_1991	-0.06	-0.14	-0.14
	(-0.54)	(-1.35)	(-1.38)
ln(n+g+d)	-3.09	-5.75	-4.36
	(-0.59)	(-1.23)	(-0.77)
ln(Kg)	0.23	0.31	0.53
	(1.17)	(2.00)	(3.30)
ln(Sec)			0.00
			(0.46)
ln(Kg)xln(Sec)	0.20		
	(1.59)*		

[3] N. Yoshino and U. Abidhadjaev, "Explicit and Implicit Analysis of Infrastructure Investment: Theoretical Framework and Empirical Evidence", *American Journal of Economics*, vol. 6, no. 4, 2016.

ln(Uni)			0.21
			(2.07)
ln(Kg)xln(Uni)		0.24	
		(2.76)***	
Constant	-0.28	0.56	0.48
	(-0.33)	(0.69)	(0.57)
Number of observations	44.00	44.00	44.00
R-squared	0.21	0.30	0.30
F-statistic	2.62	4.14	3.29

Note: Infrastructure Investment together with secondary school and university education show positive impact on regional GDP

Investing in infrastructure that provides stakeholders – including investors, government, landowners, farmers, and entrepreneurs – opportunities for higher education and other technical training programs will lead to a higher regional GDP, as shown by Yoshino and Abidhadjaev.[4] A more modern approach to education that incorporates the use of mobile phones will allow technological advancements to take hold. From here, various subjects and programs such as science, technology, education, and mathematics (STEM), and technical and vocational training (TVET) will be able to progress as innovations contribute greatly to their effectiveness. In the past, those seeking quality education and training programs were forced to attend exclusive private schools, which generally have competitive admission processes and expensive tuition fees. Recently, there have been many advancements in technology, and it has expanded globally, becoming more accessible to many people even in developing countries.

As the Covid-19 pandemic has demonstrated, governments need to provide the necessary infrastructure to ensure that everyone is able to access the Internet. Although the pandemic

[4] Ibid.

saw lockdowns and economic shutdowns, the digital world was able to remain active. The Internet has allowed students and those keen to explore new areas of study or work a chance to listen to lectures and learn from experts from all over the world, irrespective of their geographical location. This is just one example of how investments in digital infrastructure will generate spillover effects, enabling people to stay connected and have access to educational opportunities that continue to drive sustainable development.

Infrastructure and Climate Change

Climate change will undoubtedly affect infrastructure development, but it also allows for building resilience to those impacts and working towards sustainable development. In a study conducted by the OECD, a model showed the potential impacts that a major flood in Paris could have on infrastructure, which would suffer between 30% and 50% of the damages. There would also be between 35% and 85% in business losses due to the suspension of transportation and electricity supply because of inadequate infrastructure.[5] This is where it is important for policymakers and developers to consider investing in climate-resilient infrastructure to decrease the chances of such a domino effect taking place, ultimately reducing both direct losses and the associated costs that will ensue. As the urban sprawl continues to expand across the globe, so too will investment needs in infrastructure.

Investing in quality and sustainable infrastructure that addresses the impacts of climate change is especially important in developing countries. Thus, it is imperative for leaders to take action and invest in infrastructure that is both sustainable and supports the transition to greener economies. Nonetheless, developing countries struggle with building new infrastructure

[5] Organisation for Economic Co-operation and Development (OECD), *Climate-resilient Infrastructure*, 2018.

to support sustainable urbanisation, access to energy, potable water, and connect people both physically and digitally. Moreover, these same countries, which are often the most susceptible to extreme weather events and other effects of climate change, need infrastructure for the purpose of managing these risks. Conversely, developed countries need to invest in upgrading existing infrastructure, especially to reduce GHG (greenhouse gas) emissions and increase efficiency.

Infrastructure should be planned in such a way that it foresees changing climate conditions (e.g. increasing temperatures, rising sea levels, frequency and intensity of natural disasters, precipitation patters, etc.), anticipates the disruptions that they bring about, and reduces risks as much as possible. To achieve these goals, infrastructure needs to be built to be resilient, so that it can not only endure, but also be respond, and recover quickly. Climate-resilient infrastructure can be categorised into two groups: structural adaptation measures and management adaptation measures,[6] both of which need to be invested in. Structural adaptation measures refer to infrastructure that will be able to withstand the physical impacts of climate change. On the other hand, management adaptation measures – those that are non-structural – include assessing, monitoring, and planning ahead to avoid social and economic losses resulting from climate change.

A common misconception with infrastructure such as highways and other transportation is that this will lead to increased greenhouse gas emissions. However, as previously mentioned, infrastructure can be climate-resilient and built to help mitigate the effects of climate change, with minimal impacts on the environment. Such types of infrastructure should not be blamed for a rise in emissions. Policymakers are responsible for developing regulations on the automobiles and trains that will be using the infrastructure. This can be done

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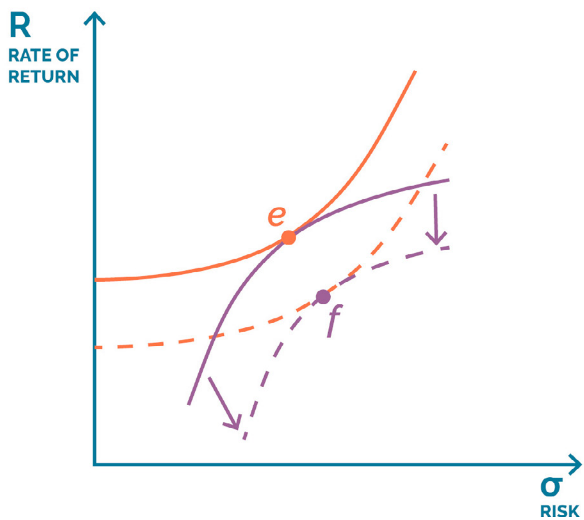
[6] European Financing Institutions Working Group on Adaptation to Climate Change (EUFIWACC), Integrating Climate Change Information and Adaptation in Project Development, European Investment Bank, 2016.

through setting standards for car manufacturers and private railway companies to remain below a certain threshold for their GHG emissions. Taxes on CO_2 and polluted gas emissions will reduce after tax rate of return for investors, which in turn will reduce the attractiveness of environmentally unsustainable companies and re-direct their portfolio to greener companies. The potential benefits that infrastructure can bring to a region are insurmountable, and as mentioned earlier, will allow rural areas to be better connected to urban hubs, increasing their market accessibility and range, ultimately increasing GDP into the region.

Fig. 1.2 - International GHG taxation scheme



Financing for Infrastructure – Turning Risks into Economic Opportunities via Spillover Effects

To meet infrastructure needs, sufficient funds need to be allocated for planning and development. Globally, with current investment trends, it is projected that there is a cumulative investment gap of US$5.2 trillion until 2030, which translates to US$0.35-0.37 trillion annually.[7] In the Asia Pacific region alone, there is an enormous demand for infrastructure, and as reported by the Asian Development Bank, about 6% of the total projected GDP will need to be allocated for this area.[8] In order to fulfil this need, increased public budgets will be required to carry out these development projects.

Even before the Covid-19 pandemic, public funds were not sufficient for meeting infrastructure needs. Especially in the post-Covid-19 recovery era, public budgets will be severely constrained due to increased spending, which accounts for stimulus packages, improved health care systems, retail, and the tourism industry, among others. With governments committed to assisting the most vulnerable, business owners, and the industries hit the hardest by the pandemic, funding will inevitably be taken away from what would have otherwise been allocated for infrastructure development. At the same time, a decrease in business activity will mean less government revenues from taxes. This will also be detrimental for existing infrastructure, which requires funds for maintenance and operational costs. Without the proper maintenance, this could potentially lead to more serious problems such as malfunctioning of infrastructure, interrupting services, business, and costing more money in the end. Even though some countries may try to compensate these deficits with the issuance of governments

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[7] J. Woetzel, N. Garemo, J., Mischke, M., Hjerpe, and R. Palter, *Bridging global infrastructure gaps*, McKinsey Global Institute, 2016.

[8] Asian Development Bank, *Meeting Asia's Infrastructure Needs*, Manila, Asian Development Bank, 2017.

which can be purchased by central banks to finance recovery, infrastructure financing will still be severely affected, in both the short and long-term, if other sources are not tapped into.

In this situation, attracting private investors to finance these projects will be crucial, particularly if countries want to continue growth and development amid other setbacks brought on by the pandemic. By investing in infrastructure, governments will be able to increase regional GDP for the affected areas in which the project was built. This can be achieved as a result of spillover effects that are generated by investments in quality infrastructure, which can then be recycled back to the government and private investors and support expansion of development projects throughout the region.

Before spillover effects can be generated, governments first need to find ways to bring private investors into the picture. In many cases, finding innovative approaches for attracting private investors has been a challenge due to the associated risks, which include political, construction, operational and maintenance, and environmental risks.[9] This section will assess the different risks and then propose solutions for minimising them.

Minimising risks associated with infrastructure investments

1. There remains some criticism over the lack of governance of infrastructure investment. Therefore, bringing in private investors and multilateral development banks can help to take the burden off of government and distribute the ownership of the project. In developing countries, political corruption is often associated with investments in infrastructure, particularly in the land acquisition stage (Figure 1.3).[10] Acquiring the land the infrastructure will be

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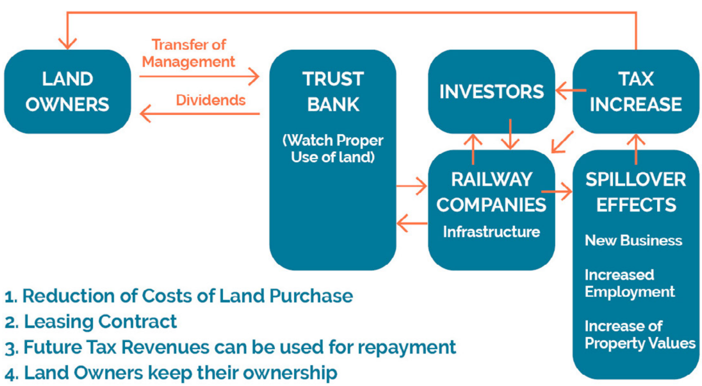
[9] N. Yoshino, N. Hendriyetty, S., Lakhia, and W. Alwarritzi, *Innovative Financing for City Infrastructure Investment by Increasing the Rate of Return from Spillover Tax Revenues*, ADBI Working Paper 979, Asian Development Bank, July 2019.

[10] N. Yoshino, N. Hendriyetty, and F. Taghizadeh-Hesary, "How a Big Impact from Covid-19 on SME Finance & Infrastructure Maintenance Can be Avoided", *Japan Spotlight*, July/August 2020, pp. 64-67.

built on often presents challenges for developers. In developing countries, informal groups sometimes become involved in this process, demanding higher prices. They act as the middleman between infrastructure companies and landowners, taking a huge cut for themselves. To address the first risk that private investors of infrastructure projects face – that related to governance and politics – land trusts should be introduced. Through the establishment of land trusts, transactions will have more transparency and the integrity of all parties is maintained. In this way, the land will be leased to infrastructure companies and landowners will be able to retain ownership.

Other governance risks exist on the political side, such as when there is a change in leadership or parties. This may interfere with the development of certain projects that may have been supported under the previous leadership. Such opposition can cause delays, leading to increased costs and other unanticipated expenses, providing another reason why it would be important to bring private investors into the picture, since they are not influenced by such changes.

Fig. 1.3 – Land trust for infrastructure investment



Source: 2020 Japan Spotlight

2. Additionally, the long timelines required for completing infrastructure projects are not particularly attractive for private investors. In most cases, this issue presents risks for private investors since they are not guaranteed any return on their investment and the economic multiplier effects work to increase tax revenue.[11] Moreover, in the early stages of the project, once the construction starts, there is little to no return on investments, making it difficult for private investors to continue to finance as they get deeper into the construction phase. Once completed, there are low rates of return since revenue usually comes only from user charges. To overcome these obstacles, governments can provide revenue bonds, offering an alternative to the traditional bank loans. Bank loans have been one of the constraints to expanding private investments in infrastructure since they are not long-term and do not cover the entire planning and construction phases of a project.

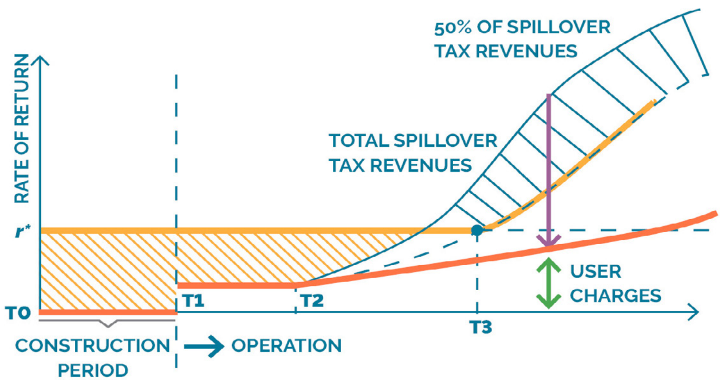
One way to address this issue is through the introduction of floating-interest-rate infrastructure bonds, which ensure that investors will be paid during the construction phase and initial stages of operation once the project is completed. Unlike the traditional government bond that carries a fixed interest rate, this floating-interest-rate infrastructure bond will pay a floating interest. This rate can fluctuate and is dependent on the spillover tax revenues.

In the situation where user charges and the return from spillover tax revenues are lower than the government bond's fixed rate, then the interest will be matched to that of the government bond. This ensures that the infrastructure investors will receive interest equal to the government bond, which is the lowest rate. Moreover, this type of bond will distribute the spillover tax revenues generated by the infrastructure between the government and investors. Once the spillover effects from the infrastructure start to accumulate, investors will get a higher return compared to the initial fixed-rate government bond.

[11] N. Yoshino, N. Hendriyetty, S., Lakhia, and W. Alwarritzi (2019).

The success of this type of bond is dependent on the spillover effects, transparency, and accountability of the project. This kind of bond will help to promote more bankable infrastructure projects and attract the necessary private investors to help finance them (Figure 1.4).[12] Big hydro-projects are typical example of big spillover return which will help regions ensure electricity supply. Electricity supply will bring new businesses, restaurants and new residential apartments which will increase sales tax, income tax and property tax etc. Floating rate bonds can be most suitable in these large scale projects.

FIG. 1.4 - INFRASTRUCTURE FLOATING INTEREST RATE BOND



3. Operational and maintenance costs are also expensive and deter private investors. Maintenance is often not adequately prioritised in infrastructure planning and too little is spent on maintaining existing facilities, relative to investments in new infrastructure. This presents additional challenges to efficient spending and places additional stress on public finances.[13] Since

[12] N. Yoshino, D. Azhgaliyeva, and R. Mishra, "Financing infrastructure using floating-interest-rate infrastructure bond", *Journal of Infrastructure, Policy, and Development*, vol. 4, no. 2, 2020, pp. 306-315.

[13] D.H. Brooks, "Infrastructure's role in lowering Asia's trade costs", in D.H. Brooks and D. Hummels, *Infrastructure's Role in Lowering Asia's Trade Costs: Building*

user charges are generally quite low and unreliable, they do not cover the costs to continue providing quality service and maintenance of the service linked with the infrastructure.

4. Lastly, environmental risks must also be addressed. As society shifts towards greener investments, increased pressure will be put on private investors to follow suit. Since infrastructure projects are not always associated with the idea of being green, especially when it comes to roads and railways, it is important that stakeholders understand the positive impacts that will result from the infrastructure. However, this is not to say that environmental impacts and GHG emissions should be overlooked, rather it should be noted that these greenness issues can be addressed by imposing GHG tax on companies with a poor environmental record. Global taxation with the same tax rate will shift to environmentally friendly industrial structures.

For example, some might say that constructing a new road or railway would lead to more cars, translating to increased GHG emissions, further adding to climate change. However, the infrastructure itself should not be blamed. Policymakers need to collaborate with stakeholders including scientists and the private sector to push for improved technology. If green technologies were developed at a much faster pace, imposed taxes on GHG will be drastically reduced.

At the same time, as mentioned in the previous section, infrastructure should be sustainably built, taking into account the effects of climate change, and minimising impacts on the environment. This can be achieved through selecting infrastructure projects that help to meet the demands of the changing climate and requires better assessment of its impacts, through thorough certified environmental impact assessment procedures. Another approach to minimising environmental risks is to invest in developing infrastructure that promotes the use of renewable energy. Recent investments in this area include transitioning from outdated technologies that have

for Trade, Cheltenham, Edward Elgar Publishing Limited, 2009.

higher GHG emissions to those that are less reliant on fossil fuels, increasing access to cost-effective energy (especially in developing countries and rural areas), and accelerating research and development.

A Way Forward

As countries continue to search for innovative approaches to help their economies and the livelihoods of their citizens recover from the Covid-19 pandemic, infrastructure investments cannot be overlooked, particularly those in sustainable and quality infrastructure. Infrastructure development will help the economy to rebound by creating new business opportunities, increased connectivity both physically and digitally, improved living conditions, especially in developing countries, and will help address remaining poverty and reduce inequality.

However, to alleviate the increased budget constraints on public finances, which have seen skyrocketing deficits due to the pandemic, it becomes necessary to tap into alternative sources of infrastructure financing. Attracting private investors through floating-interest-rate infrastructure bonds and highlighting the shared spillover effects from tax revenues will make investing in sustainable and quality infrastructure more lucrative. With support from the private sector, policymakers will be able to better promote sustainable development their respective regions. Greenness of infrastructure can be achieved by global taxation on polluting gases and waste, which will encourage green activities on the part of various companies. Increases of greenness efforts will increase after-tax rate of return, thus attracting more private investors into the company.

2. The Challenge To Attract More Private Investments and Institutional Investors for Sustainable and Green Infrastructure: What Is Needed?[1]

Raffaele Della Croce

The quality and design of infrastructure[2] play a key role in shaping how we live, what we do, and how we interact in almost every aspect of our lives. They determine economic structures and outcomes, social systems, personal well-being, environmental impact and development pathways. Investment in sustainable and quality infrastructure, implemented through appropriate delivery mechanisms and managed efficiently over the life cycle, contributes to economic development, and enables the achievement of ESG objectives and the Sustainable Development Goals (SDGs). In fact, goal 9 of the SDGs calls for the development of "quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human

[1] This brief is adapted from the chapter "ESG and Institutional Investment in Infrastructure" published as part of the 2020 OECD *Business and Finance Outlook* (BFO) launched in September 2020 and focusing on sustainable and resilient finance. This work contributed to the Long-Term Investors@UniTo (LTI@UniTO) and Università di Torino.

[2] The OECD defines infrastructure as the system of public works in a country, state or region, including roads, utility lines and public building – in essence the tangible backbone of essential goods and services underpinning an economy. See: OECD, Glossary of Statistical Terms, "Infrastructure".

well-being, with a focus on affordable and equitable access for all". Responses to the Covid-19 shock for economies and societies are expected to include renewed infrastructure investment as a stimulus measure. This presents an opportunity to steer the infrastructure sector onto a more resilient and sustainable path, avoiding a "lock-in" of fossil fuel infrastructure and carbon-intensive assets. Investment needs to be in line with the Paris Agreement, including decarbonising industry and transport, building smart energy systems, and increasing access to affordable, clean energy. In the International Energy Agency (IEA) Sustainable Development Scenario for example, spending on renewable power would need to double by the late 2030s.[3]

As governments make efforts to promote sustainable and quality infrastructure investment, they are also seeking to mobilise private capital to meet large infrastructure investment needs, and so achieve more ambitious development, sustainability, and resiliency objectives. A study by McKinsey (2018) estimated that roughly US$1.6 trillion of renewable power investments will be made available to institutional investors by 2030.[4] Roughly 70% of that investment opportunity will be composed of unlisted assets that do not trade publicly.

Over the years, institutional investors (which include pension funds, insurers, and sovereign wealth funds) have made allocations to infrastructure, largely driven by a search for greater diversification and improved yields. The infrastructure financing market has in fact gone through a radical transformation since 2005. A number of factors, such as a changed macroeconomic environment, more stringent regulations on financial intermediaries, and a modified appetite for long-term asset investments, have led to a reallocation of

[3] IEA and Imperial College, *Energy Investing: Exploring Risk and Return in the Capital Markets*, Imperial College Business School, London; A. Bardalai and R. Della Croce, *Financing Low-Carbon Infrastructure*, City UK and Imperial College Business School, London, November 2019.

[4] McKinsey Global Energy Perspective (reference case 2019).

flows from the banking sector to the institutional investor sector.[5]

The momentum toward greater involvement of institutional investors in infrastructure investment continues. For instance, at the start of 2020, with over 250 infrastructure funds collectively seeking more than US$200 billion from investors – double the total capital targeted at the start of 2015 – strong growth in infrastructure AUM is expected to continue.[6] Ultimately the primary concern for institutional investors is investment performance within the scope of their specific objectives (such as paying pensions and annuities). Infrastructure can keep growing as an alternative asset class for private investors provided that investors can access bankable projects and an acceptable risk/return profile is offered.

Institutional Investment in Green Investment and Low-Carbon Infrastructure

The integration of ESG factors into investment decision-making and risk management, including for infrastructure investment, is part of a broader trend among institutional investors to adopt sustainable investment strategies, which also include divestment, corporate engagement, sustainability themed investment, and impact investing, among others. Sustainable investing assets stood at US$30.7 trillion at the start of 2018, a 34% increase in two years; in certain regions it accounts for a sizeable share of professionally managed assets, from 18% in Japan to 63% in Australia and New Zealand.[7]

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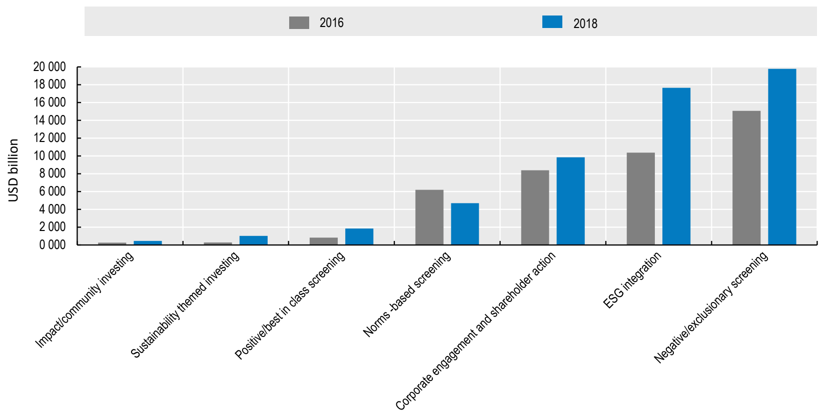
[5] When looking at specific infrastructure allocation, it has been through unlisted equity vehicles that the characteristics of the infrastructure asset class have been formulated. As of December 2019, the infrastructure fund industry holds US$631 billion in infrastructure assets, up from just US$129 billion at the end of 2009 (see Preqin, *2020 Preqin Global Infrastructure Report*, 2020).

[6] Ibid.

[7] GSIA, *Global Sustainable Investment Review 2018*, The Global Sustainable Investment Alliance, 2018.

Sustainable investments extend across the range of public and private asset classes commonly found in diversified investment portfolios. The latest Global Sustainable Investment Alliance (GSIA) report on sustainable assets shows that in 2018, 51% of total US$31 trillion assets were allocated to public equities and 36% to fixed income with the remaining 13% in private markets in alternative asset classes such as real estate, private equity and infrastructure (Figure 2.1).[8] There are a variety of investors in sustainable investment with different objectives and mandates among the most active institutional investors, such as pension funds and insurers. Some investors examine ESG factors mainly through the risk management lens as an opportunity for higher financial returns, while others perceive ESG factors as non-financial objectives, such as carbon emissions or other sustainability-performance targets, that they wish to promote.[9]

Fig. 2.1 - Global growth of sustainable investing strategies, 2016–2018



Source: GSIA (2018)

[8] The GSIA survey shows asset class allocation in Europe, the United States, Japan and Canada in 2018. Sustainable investments can also be found in hedge funds, cash or depository vehicles, commodities. GSIA (2018).

[9] *Sustainable and Resilient Finance. OECD Business and Finance Outlook 2020*, OECD, 2020.

Corporate engagement or shareholder action is a popular and growing strategy among infrastructure investors in private markets. Infrastructure equity investors often have controlling stakes in the business, allowing significant scope for corporate engagement – limited though by the contractual nature of the services provided. Although a debt investor has less control over the operations of its assets compared to an equity investor, there are several ways debt can support equity to be more sustainable, including through setting conditions prior to funding and/or covenants related to the remediation of ESG risks. Projects may also need specific covenants related to environmental considerations, construction permitting, and post-closing remediation monitoring.

The range of active strategies focused on sustainability as an investment outcome includes thematic and impact investing, and it is important for infrastructure. Although starting from a low base they have seen huge growth in recent years with themed investing accounting for US$1 trillion in 2018, up from less than US$280 billion in 2016.[10] Environmental factor integration achieved via impact and themed investing is relevant for infrastructure as it may include social infrastructure or renewable energy projects, green bonds and companies addressing environmental issues.[11]

Regulatory requirements related to ESG are a key driver and have increased the use of ESG considerations in infrastructure investment. Funds are also adjusting to new regulations in some markets that seek to clarify the role of ESG in a fund's investment process. This is part of a broader policy and regulatory push to

[10] For example, AllianzGI has a traditional infrastructure allocation in unlisted markets but also an infrastructure equity team that is dedicated to green energy assets. BlackRock currently manages a US$50 billion fund that supports the transition to a low-carbon economy, including renewable power infrastructure business, which invests in the private markets in wind and solar power, and green bond funds. GSIA (2018).

[11] OECD, *Sustainable and Resilient Finance. OECD Business and Finance Outlook 2020*…, cit.

clarify and disclose climate-related risks in the financial sector, which provides an indirect push for asset owners (and asset managers, who may manage their investments) to consider climate and other ESG-related risk factors, given potential exposures through their investments.

These regulations and policy initiatives have put added pressure on the investment community to improve ESG reporting and have also forced investors to consider long-term risks associated with ESG factors, including future regulations or policies that might impact their infrastructure assets. A growing number of investors concerned with the potential impact of sustainability on their long-term financial performance are involved in initiatives for the voluntary disclosure of ESG practices.

A number of countries has put in place reporting requirements for the disclosure of ESG practices by institutional investors, which may have implications for the application of ESG practices on infrastructure investments held in portfolios. For instance, Australia requires pension funds, insurance companies, and asset managers to disclose their ESG practices. France has introduced the most far-reaching requirements in terms of ESG reporting by institutional investors. Under Article 173-VI of the Energy Transition Act, asset managers, pension funds and insurance companies must provide information not only on how they integrate ESG factors into their investment and voting decisions but also on the climate risks they face and how their portfolio construction contributes to the transition to a low-carbon economy.

Furthermore, the adoption of ESG factors in infrastructure investment is enabling impact-oriented institutional investors to screen and select projects, funds, and companies, and align their infrastructure investments with sustainability objectives that are consistent with return objectives. This alignment may be based on principle but it may also be motivated by a view of sectoral growth opportunities or as a way to avoid or manage certain types of risks, such as asset stranding.

Barriers to ESG Investment in Infrastructure

Pension funds and insurance companies are increasingly choosing to integrate ESG factors into their investment decisions but major challenges remain.[12] Major barriers to ESG integration are also obstacles to the development of better risk management strategies for investors and the allocation of finance to infrastructure investments. Infrastructure investing has different characteristics to other asset classes, with specific barriers to ESG investment and analysis.

ESG factors often lie beyond the time horizons of investors and policy misalignments or market failures (such as the disconnection of risk pricing) do not provide correct market signals.[13] Specifically for private markets and infrastructure, further complications include the capabilities and expertise of investors, potential short-termism due to market structures (for example, the principal-agent issue between asset owners and asset managers), and a lack of financial data and track records on the financial and ESG performance of infrastructure projects.

ESG factors can present risks across the infrastructure lifecycle – from the pre-construction phase through to the operational phase – for financing providers, from banks to asset managers and institutional investors. Furthermore, the central role of infrastructure in economic and social activities, and its broader environmental and social impacts, may serve to accentuate ESG risks, by introducing policy, regulatory, and reputational risks.

ESG approaches adopted by investors will vary depending on how infrastructure investment is accessed, taking into account that the preferred route to infrastructure investment in the last decade has been through unlisted equity. In private markets, for pension funds and other institutional investors not

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[12] OECD, *Sustainable and Resilient Finance. OECD Business and Finance Outlook 2020*…, cit.

[13] As seen in previous chapters there is increasing evidence of market inefficiencies in pricing ESG risks.

capable of investing directly, hiring external consultants and asset managers to manage infrastructure investment has been the preferred way to access this asset class. Principal-agent issues between short-term private equity asset managers and long-term asset owners could cause disincentives to the adoption of ESG factors in the investment process.

The fact that infrastructure investment is often undertaken through private markets makes the adoption of ESG decision-making more challenging, as private markets do not have the same disclosure requirements as public markets. Given the often indirect nature of their infrastructure investments, through funds or managed separate accounts, institutional investors must rely heavily on their asset managers and other service providers to track their exposure and performance. Hence asset managers play a key role in implementing and measuring ESG criteria in the portfolios of institutional investors.

Despite broad recognition of the importance of ESG criteria and interest in incorporating these factors into infrastructure investment decision-making, the implementation of these criteria in asset valuation remains at an early stage. Several international standards and tools have been developed to integrate sustainability and resilience aspects into infrastructure development and support ESG infrastructure asset analysis. Current methods for ESG measurement and ESG-related analysis vary among stakeholders at different phases in the infrastructure process. Despite the number of initiatives, there seem to be several problems with the analysis of ESG factors in infrastructure. Among the major issues are: the lack of a common definition and metrics for measuring exposure to ESG in infrastructure; the lack of quality data and information required to perform analyses; the ability to quantify ESG criteria in financial terms; transparency in valuation methodologies across the industry; investors' understanding of and confidence in ESG valuation; and the cost of ESG analysis.

ESG and Infrastructure Investment Performance

While there is increased investor interest in adopting ESG approaches, the links between ESG factors in infrastructure and infrastructure investment risks and returns is not well understood, and the literature is nascent. Some findings from general ESG literature may be relevant; for instance, as regards energy infrastructure, the shares of renewables over the past decade offered higher total returns than fossil fuels, with lower annualised volatility (a measure of investment risk).[14]

The impact of ESG factors on financial performance is a central issue in the debate around sustainable investment. The long-term nature of infrastructure investments means sustainability and resilience-related risks could potentially have a major impact.

Some studies suggest ESG approaches tend to reduce risks and generate higher returns through an "ESG factor" driving the performance of companies.[15] For example, Franz Fuerst (2015) regressed Global Real Estate Sustainability Benchmark (GRESB) scores on various REIT financial indicators such as ROA and ROE in order to test the link between sustainability and financial performance.[16] The study found that there was a positive relationship between the sustainability score and the profitability of real estate companies. The study attributed these results to gains in operating performance, efficiency, and lowering risk exposures.

[14] The IEA and Imperial College London are investigating the risk and return proposition available to investors in the energy sector through a series of special reports. The first study focuses on historical financial performance of fossil fuels versus renewable power in listed equity markets of select advanced economies. The methodology used in the report will be extended to other countries and unlisted (i.e. private market) investments in forthcoming work. IEA and Imperial College Business School (2020).

[15] See Amundi, *The alpha and beta of ESG investing*, 15 January 2019.

[16] F. Fuerst, *The Financial Rewards of Sustainability: A Global Performance Study of Real Estate Investment Trusts*, SSRN, 16 June 2015.

While recent OECD analysis finds mixed evidence of the impact of ESG performance on financial performance broadly,[17] the long asset life cycles and investor timelines may expose infrastructure assets to particular ESG risks which are material to investors. However, data on infrastructure is often lacking and not comparable as it is not being reported in a standardised format or audited by external auditors. Also, the same company can receive divergent ESG ratings, due to problems of inconsistency of criteria and misrepresentation through one single metric of the impact of multiple ESG factors.

As reporting is still immature, scoring has focused on a firm's management approach and transparency of performance rather than direct performance. A recent study by EDHEC cross-references for the first time the ESG scores computed by GRESB Infrastructure and the financial metrics of the EDHEC infra universe, showing that ESG ratings are not positively or negatively correlated with returns, suggesting that the adoption of ESG investment approaches should not harm returns (no trade-offs) but also challenging the notion that ESG is a risk factor.[18]

Recent OECD discussions with asset managers[19] active in infrastructure investments and creating infrastructure funds for institutional investors revealed a consensus on the view that ESG factors are essential for effective risk management of infrastructure assets (especially to protect against downside risks) to preserve and enhance asset value over time.[20] It was argued that consideration of ESG factors or other sustainability considerations in infrastructure is still underdeveloped relative to other asset classes. The environmental aspect is reportedly

[17] OECD, *Sustainable and Resilient Finance. OECD Business and Finance Outlook 2020*…, cit.

[18] EDHEC, Infra300 equity index (local returns), First quarter 2020.

[19] From an OECD Dialogue with the Asset Management Industry on Sustainable Infrastructure, 25 October 2019.

[20] See also OECD, *G20/OECD Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure: Investor proposals and the way forward*.

the most concrete, whereas "S" & "G" measures are less clearly defined. It was noted though that "S" and "G" components are already embedded in regulatory mechanisms governing infrastructure development. These discussions also revealed the limits of the management of ESG risks in infrastructure; as institutional investors often acquire assets after they are built (i.e. brownfield infrastructure), there may be limited scope for them to influence ESG factors, highlighting the importance of incorporating such factors upfront in infrastructure procurement decision-making and the need for investors to include these factors in investor due diligence.

Catalyse Institutional Investors for Low-Carbon Infrastructure

As many fiscally constrained governments seek greater levels of private finance in infrastructure, there is a growing need to leverage private financing and "blend" scarce public money with private resources through various instruments (investment grants, interest subsidies, and first-loss guarantees). Governments are focusing their efforts on being more innovative in the way they fund projects, using new financial instruments and techniques, and optimising risk allocation among the respective stakeholders. This is particularly important in developing economies where investment is sometimes further hindered by weak policy frameworks and governance.

Despite the positive net contributions of certain investments to economic welfare, market failures and differing incentives can prevent investors from taking certain risks and/or making certain investment decisions. A key role for the public sector is to leverage the government balance sheet through risk mitigation instruments for infrastructure projects and attract private sector capital. Financial instruments create a multiplier effect for public funding by facilitating and attracting other public and private financing for projects. The use of innovative instruments can be expanded in order to stimulate knowledge-sharing, critical mass, economies of scale, standardisation and risk sharing among project stakeholders.

State-owned infrastructure banks, as well as development or green banks and finance institutions (NDBs, MDBs and bilateral DFIs and Export Agencies) are playing an increasing role in accelerating private sector investment in green infrastructure and developing secondary markets for sustainable infrastructure. Through their actions they aim to (i) use blended finance investing alongside the private sector to crowd-in investment; (ii) improve liquidity in the secondary market; and (iii) signal to the investors the community and national commitment, and the future opportunities for refinancing and acquisition.

Conclusion

Given the central role played by infrastructure in our economies and societies, and its broad economic, social, and environmental impacts, delivering quality infrastructure requires, among other things, gaining community support and the social licence to operate, highlighting the relevance of ESG factors for infrastructure investment. As institutional investors gain exposure to infrastructure through their portfolio investments, as providers of infrastructure financing, and start adopting ESG strategies for their investment portfolio(s), there is increasing recognition that ESG factors are relevant for infrastructure investments – in particular for the management of risks, to ensure downside protection and preserve if not enhance asset value over the holding period.

For governments in many countries, implementation of quality infrastructure investment is a key priority, which requires, among other things, relevant ESG considerations to be taken into account in government procurement decisions, in the agreements governing public-private partnerships for new projects, and in the conditions attached to budget facilities for infrastructure. Policy settings can also help to overcome key challenges or issues that impede proper private investor consideration of ESG factors in asset-level analysis of infrastructure, to the extent that the industry is unable to resolve the issues. Suggestions for government action have included better disclosure of private project-level data to investors, governments sharing their own project data, better government communication of priority ESG elements in infrastructure,[21] and clear, consistent and broader guidance regarding ESG disclosures in financial markets.

A holistic framework aligning objectives and definitions among stakeholders is needed. In order to differentiate among the effects of different ESG factors, investors and regulators need more granular data. There is a need to better understand the link between ESG and financial performance, especially on long-term effects and materiality and on asset allocation trends in private markets for infrastructure.

Given the shared interest in the effective management of ESG risks, so as to ensure positive social and economic outcomes for infrastructure investment, further progress could benefit from closer collaboration involving key stakeholders from private and public sectors, to enable dialogue and the identification of priority actions. As part of this dialogue, understanding investor motivations, ESG approaches and methodologies used for infrastructure, and data requirements, accessibility, and limitations would be valuable. Such collaboration could feature as part of broader current G20 and OECD efforts at public and private collaboration on infrastructure, undertaken with multilateral development banks, the GIH, and other stakeholders; indeed, ESG issues have already been identified as an important topic.[22]

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[21] See OECD, *Sustainable and Resilient Finance. OECD Business and Finance Outlook 2020*…, cit.

[22] See OECD, *G20/OECD Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure: Investor proposals and the way forward*…, cit.

3. Transition Finance and Climate Resilient Infrastructure, an Opportunity To Build Back Better

José Luis Reséndiz

Infrastructure has supported fossil-based economies for decades, bringing positive outcomes such as jobs, innovation, and economic growth. However, our planetary boundaries make such an economic model unsustainable for the near future. Therefore, we will need an unprecedented transformation of global infrastructure to face upcoming climate disasters and speed up the transition towards a net-zero economy. The current climate crisis implies a capital replacement problem.[1] Since renewable energy is already competitive enough to replace fossil fuels, the upcoming challenge is substituting all the assets that depend on dirty energy sources. Consequently, the transition towards a net-zero economy will require massive capital to finance a wide range of assets, such as infrastructure systems, the major contributors to greenhouse gas (GHG) emissions.[2]

For this purpose, infrastructure plays a critical role in speeding up or slowing down any credible transition, namely one that is aligned with the Paris Agreement targets.[3] For instance,

[1] T. Thygesen, E. Mathiesen, K. Dige Ovesen, and C. Lehmann Christiansen, Capital replacement and transition arbitrage, Climate & Sustainable Finance Research, Skandinaviska Enskilda Banken (SEB), January 2021.

[2] D. Saha, "Low-carbon infrastructure: an essential solution to climate change?", World Bank Blogs, 5 April 2018.

[3] Climate Bonds initiative (CBI), Financing credible transitions. How to ensure

carbon-intensive infrastructure such as new large-scale pipelines for oil and gas can delay the transition of entire regions, since the value chains will still depend on fossil fuels for decades to come.[4] By contrast, charging stations for electric vehicles can accelerate their production. Therefore, infrastructure plans should be embedded in the growing number of net-zero pledges since they will pave the way for the usage of new low-carbon technologies. In addition to the challenge of identifying the best infrastructure for successful decarbonisation, there is also the concern about the source of funding for these large-scale projects.

This chapter outlines how to identify and finance a transitioning infrastructure to a net-zero economy, mainly through sustainable debt capital markets. Furthermore, through an innovative approach called transition finance, we aim to unearth effective mechanisms to finance ambitious decarbonisation strategies in the infrastructure sector. Additionally, our scope considers low-carbon climate-resilient (LCR) infrastructure, which refers to projects that will either mitigate GHG emissions and/or support adaptation to climate change in three sectors: transport, energy or building.[5] Some examples include renewable energy technologies, electricity networks, energy efficiency innovations for buildings and transport.

Furthermore, we aim to point out the main challenges and opportunities that the sustainable bond market is facing in the infrastructure sector to support a credible transition towards net-zero. Unfortunately, investing in green technology does not equal greening the world. There is a growing debate about what constitutes a green financial service or product and

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the transition label has impact, A joint Climate Bonds & Credit Suisse (White Paper), Credit Suisse, 2020.

[4] Congressional Research Service (CRS), Keystone XL Pipeline: Overview and Recent Developments, April 2015.

[5] OECD, Climate-resilient Infrastructure, Policy Perspectives, OECD Environment Policy Paper no. 14, 2018.

how to improve their greenness by meeting two conditions: encouraging green activities and inhibiting brown ones, and reducing greenwashing risks. Beyond improving and replacing infrastructure, it is critical to ensure we are not adding further GHG emissions with the current deployment of infrastructure not aligned to a net-zero economy.

Infrastructure Aligned with a Credible Transition

LCR infrastructure investment is fundamental to delivering net-zero emissions by 2050 since it makes two significant contributions: accelerating the low carbon technologies' deployment and improving climate change adaptation.[6] A credible transition pathway should prioritise the energy systems' transformation, which is the solution for three interlocking problems in the short term: climate crisis, social stability and under-investment. While water and telecommunications' infrastructure contribute to emissions reductions, the energy, transport, heat and harder-to-abate sectors can achieve the most outstanding contribution to avoid climate disasters.[7] Therefore, deploying infrastructure to consolidate a clean energy system should be the priority for any country in the coming decades. By doing so, we can expect a significant reduction in GHG emissions while creating jobs and raising wages.

At the moment, wind and solar energy technologies are more competitive than fossil sources.[8] Yet, affordable clean energy constitutes the first stage towards a net-zero economy. To avoid a greater climate disaster, we will require replacing the assets in which fossil fuel input is embedded. Hard-to-abate sectors

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[6] R. Della Croce and A. Bardalai, Financing low-carbon infrastructure, The City UK, Imperial College Business School – Centre for Climate Finance & Investment, 2019.

[7] A. Hardy, A plan for transitioning infrastructure to net zero, Institution of Civil Engineers (ICE), 2 September 2020.

[8] International Energy Agency (IEA), World Energy Outlook 2020, 2021.

are the ones that cannot work based on electricity input due to the lack of competitive technology that can enable them to make a sustainable energy transition.[9] Furthermore, new energy infrastructure requires input from those energy users, so their activity cannot stop until affordable technologies become available.

A feasible roadmap for a successful energy transition should prioritise the electrification of supply chains. Accordingly, new technologies that allow energy users to decrease their fossil fuel dependency will need smart grids, renewable energy and storage. From where should we expect to obtain the necessary capital? The public sector has played a leading role to finance this type of infrastructure, but policymakers should promote incentive structures that attract private investors. In this regard, capital markets represent an efficient mechanism to raise funds from responsible investors interested in obtaining high returns while contributing to the energy transition.

Second, to effectively deploy renewable infrastructure, materials such as steel, chemicals and plastics will still be required. Thus, we should encourage those industries to commit to credible decarbonisation pathways based on reliable metrics,[10] including a circular economy approach to diminish waste and environmental impacts. Numerous carbon-intensive sectors do not have access to the technology required to reach net-zero emissions yet. However, each industry must commit to achieving a transformation to plug into renewable infrastructure. Therefore, the main challenge relies on the fact that several industrial activities should replace their capital stock to electrify while providing essential inputs for expanding renewable electricity supply.

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[9] Climate Bonds initiative (CBI), *Financing credible transitions. How to ensure the transition label has impact*…, cit.

[10] B. Caldecott, "Defining transition finance and embedding it in the post-Covid-19 recovery", *Journal of Sustainable Finance and Investment*, 28 July 2020.

To sum up, primary technology sectors, such as solar and wind energy generation, have already reached a cost tipping point. In the short term, the secondary technology sector that will do this next is the automotive sector.[11] Unsubsidised electric vehicles (EVs) are likely to have a similar price as traditional ones within the next five years. Following the decarbonisation pathway of different sectors enables us to identify the critical infrastructure to support that process. For instance, EVs will need an extensive network of "on-the-go" charge-ups similar to the refuelling stations that support conventional vehicles today. Places like the United Kingdom or California have announced they will ban internal combustion engine cars from 2035,[12] which will accelerate the economic viability of increasing EVs without incentives such as taxes. A conservative estimate of 5% penetration of EV in the total vehicle fleet by 2030 will require up to 60,000 charging locations with approximately 230,000 fast-charge points.[13]

Responsible investors will need to follow up on sector-specific technological breakthroughs towards net-zero. This transition will imply the constant improvement of sustainability ambitions aligned with the Paris Agreement targets and future taxonomies outlined by governments. However, being aligned with taxonomy is not enough for a credible transition.[14] Investors should consider supply chain emissions and long-term decarbonisation strategies as well. It is crucial to assume that transition will be different for each sector due to technological progress and policy regulations. From the technical perspective, energy users that cannot displace fossil fuels from their supply

[11] D. Lubin, C. Mangieri, and T. Nixon, *Transparency was the starting point but managing climate impact is about transformation*, Constellation-Calvert-CDP-3M-Reuters, 2020.

[12] P. Campbell, "UK plans to ban sale of all polluting cars by 2035", *Financial Times*, 4 February 2020.

[13] A. Singh and H. Le, "Electric vehicles and charging infrastructure. EV charging infrastructure: Redefining the road ahead", PwC, 8 March 2021.

[14] Climate Bonds initiative (CBI), *Financing credible transitions. How to ensure the transition label has impact*…, cit.

chain will need to wait until new technologies become available. After this point, the transition will be capex-intensive resulting in high profitability. At the same time, existing capital stock will face an accelerated depreciation and, eventually, be replaced.

What are the barriers to invest in LCR investment? While we identify the transition readiness of each sector, we also need to overcome the constraints around allocating capital in low carbon technologies. From a financial perspective, there are, at least, three critical obstacles that should be addressed in the short term. First, we still do not have a standard definition of climate-resilient infrastructure, making it challenging to compare infrastructure's carbon emissions. In this article, we use the OECD's definition, but various institutions offer several alternatives. The second barrier refers to the distinctiveness of projects, which refers to the complexity of comparing different LCR infrastructure projects due to regulatory frameworks, contract structures and population densities in different regions. Third, there is no validated project-level information, making it difficult to confirm the low carbon features of the initiatives. One way to overcome this issue will be developing taxonomies that define LCR infrastructure and request more specific information. Additional issues that must be addressed promptly for LCR infrastructure projects are unpriced negative externalities such as climate risks, lack of disclosure of novel technology and the associated risks, and lock-in of existing carbon-intensive infrastructure.[15]

Sustainable Debt Instruments for Transitioning Infrastructure to Net-Zero

Climate volatility and global warming are already happening, and one of the most efficient ways to mitigate those changes is through low-carbon climate resilient infrastructure. The race to net-zero involves an unprecedented effort to replace almost

[15] OECD, *Investing in Climate, Investing in Growth*, 23 May 2017.

all existing physical capital supported by fossil fuels. For this purpose, the cash flow from current operations will not be sufficient to finance the required investment. Therefore, capital markets have a critical role in raising and allocating funds. Particularly, sustainable financing debt instruments will be an essential source for green and resilient infrastructure needed for the upcoming climate disasters.

Over the past decade, green bonds have been the most developed asset class of sustainable instruments. Market participants recognise them as an effective tool of mobilising investment towards climate change mitigation and adaptation projects, including LCR infrastructure. One of the main challenges to increase investor interest in green bonds is improving metrics and standards to define the "greenness" of assets or projects. A reliable and comparable green labelling is the foundation of robust infrastructure pipelines. At the same time, progress in this field will help meet global institutional investor demand for green assets.

Green bonds are always based on use of proceeds and backed by the issuer's balance sheet. The accumulated size of the green bonds markets passed US$1 trillion in 2020, and it will continue to grow at significant rates since vast amounts of investment are needed to replace all unsustainable capital.[16] The green bonds market increased 9% in 2020 compared with 2019, and sustainability bonds -which address green and social goals- represented US$160 billion, increasing by 131%.[17] The economic and social impact of the Covid-19 pandemic is the leading cause of the rise in sustainability bonds.

The corporate sector has been historically the largest issuer of green bonds. The French gas company Engie issued the most significant corporate green bond in 2020. Additionally, Caixa Bank and Groupe Credit Mutuel issued the two largest green bonds across the banking sector, US$1.1 billion and US$0.8

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[16] Skandinaviska Enskilda Banken (SEB), *SEB Green Bond Impact Report*, 2020.

[17] Climate Bonds initiative (CBI), *Sustainable Debt Global State of the Market 2020*, 2021.

billion, respectively. Those bonds focused on green buildings, renewable energy, and low carbon transportation.[18] In contrast, government agencies dominate sustainability bonds issuance due to the pandemic response. In 2020, the most prominent issuers were North Rhine-Westphalia, Germany, and the development French Agency AFD, with US$2.8 billion and US$2 billion.

Despite the growing trend of green bonds, there is an increasing concern about greenwashing practices using the proceeds model when used on projects that are not entirely green.[19] A recent alternative innovation in the sustainable debt markets is the sustainability-linked bonds (SLBs), which try to overcome the proceeds model's issues and introduce a corporate use of proceeds linked with an incentive structure borrowing costs to sustainability performance targets. As a result, the SLBs are a particular type of financial instrument designed to support the transition to sustainable economies. In other words, some features like interest rates can change whether the issuer succeeds or fail in achieving a sustainable target.[20]

Even though the SLBs are a recent asset class, the market participants already have guidance about general features of the instruments. The Sustainability-Linked Bond Principles state that any credible SLB must include at least the selection of the Key Performance Indicators (KPIs), then proceed with calibration of the Sustainability Performance Targets (SPTs) and the characteristics of the bond.[21] Lastly, reporting and verification are needed to ensure impact. The SPTs should be rational and ambitious, the benchmark must be relevant, the KPIs must be reliable, and the strategy must be credible.

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[18] Skandinaviska Enskilda Banken (SEB) (2020).

[19] T. Thygesen, E. Mathiesen, K. Dige Ovesen, and C. Lehmann Christiansen (2021).

[20] International Capital Market Association (ICMA), *Climate Transition Finance Handbook*, 2020.

[21] International Capital Market Association (ICMA), *Sustainability-Linked Bond Principles SLBP*, 2020.

SLBs fill some gaps in the sustainable finance market as they offer more flexibility and inclusiveness. They improve confidence that the entire firm comprises its sustainable goals, and linkage between the instrument characteristics and the issuer performance offers better protection for investors.[22] Therefore, SLBs expand the opportunities for hard-to-abate sectors to access capital in order to pursue ambitious and credible decarbonisation pathways. In contrast, green bonds are an asset class entirely focus on green projects, which should be aligned to future taxonomies.

In September 2019, the first SLB issuance was made by the utility ENEL, the leading player in sustainable markets in Europe, adding 80% of sustainability-linked green bonds and loans issued in 2020. Germany is the region's leader, followed by Spain, Italy, France, and the UK.[23] Compared with sustainability-linked loans, the SLB market is still tiny, but in 2020 raised more than twice the funds it did in 2019, and the publication of ICMA's Sustainability Linked Bonds Principles has boosted this market. European corporations are the leading SLB issuers. In 2012, all issuers were European, and in 2020, only 2 out of 18 were not.[24]

What are the expectations for SLBs? According to the Natixis' (2021) investor survey, four out of five investors see SLBs as not competing with green bonds and do not seem concerned about the instrument's complexity regarding the choice of KPIs. However, the concerns regarding greenwashing risks, lack of ambition, and lack of comparability persist. Most investors agree that the KPIs should be driven by sustainability performance rather than financial considerations. Accordingly, the targets should consider transition pathways of different sectors, including high carbon emitters.

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[22] Amundi Research, *Sustainability-linked bonds: nascent opportunities for ESG investing*, 15 December 2020.

[23] Skandinaviska Enskilda Banken (SEB), *The Green Bond: Your insight into sustainable finance*, Climate & Sustainable Finance, 10 December 2021.

[24] Ibid.

Transition Finance: Improving Greenness of Infrastructure Bonds

The most critical global goal is to meet a Paris-aligned net-zero economy. For this purpose, all sectors must be engaged, and LCR infrastructure plays a crucial role in enabling the decarbonisation of sectors that are already near-zero and of hard-to-abate industries. Towards that end, a transition finance approach should guide how capital markets will shape their rules and incentives towards a sustainable and inclusive future.

Transition finance has emerged as a tool to help align the market's incentives with environmental and social sustainability goals, especially hard-to-abate sectors. Sustainability linked bonds are part of this type of asset, as they allow organisations or even countries to raise funds to develop transition projects, regardless of whether they are currently "green", as long as they have ambitions to cooperate in a sustainable manner.

Despite its rising relevance, there is not a standard accepted definition of transition finance. Defining what it is and the financial tools that comprise it is crucial to expand its use. Nevertheless, there are some valuable efforts to define and establish a framework for its operation. For instance, the Climate Bonds Initiative states that the transition label must identify sectors and companies making ambitious transitions following the pathway established to accomplish the Paris Agreement goals. The transition label is applicable at the project or entity level and is valid for hard-to-abate sectors with high current emissions.[25]

Most recent attempts to clarify the transition finance approach have promoted the idea that economic agents should pursue to achieve minimum carbon emissions reduction rates.[26] However, even if they recognised the central role of Paris

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[25] ICMA, *Climate Transition Finance Handbook*…, cit.

[26] C. Donovan, M. Fomicov, and A. Ostrovnaya, *Transition Finance Managing Funding to Carbon-Intensive Firms*, Imperial College Business School-Centre for Climate Finance & Investment, 17 September 2020.

Agreement goals, they affirm that the level of ambition in terms of frame time and reduction targets should be the decision of each financial institution, depending on the regional and sector characteristics. This kind of interpretation leaves much uncertainty about the level of ambition of the targets. Moreover, it can still be confused with the term climate finance, which refers to the financial support of the transition to a climate-resilient economy by enabling mitigation actions, especially the reduction of greenhouse gas emissions and adaptation initiatives promoting the climate resilience of infrastructure.[27]

A practical alternative framework is the Climate Transition Finance Handbook, which is more oriented to practitioners by offering guidance about green, social and sustainability-linked bonds. The handbook states that the transition label should be applied to debt financing instruments that effectively communicate the implementation of an issuer's corporate strategy to transform the business model by addressing climate-related risks while also contributing to the Paris Agreement goals.[28]

To sum up, we identify three main standard features of available frameworks and definitions: science-based alignment, flexibility and inclusiveness. The first one refers to the alignment to the climate science evidence integrated into the Paris Agreement goals or future taxonomies. Keeping global temperature below 2°C is a matter of survival and central guidance for decarbonisation pathways across sectors and regions. Second, the emergence of new asset classes such as the SLBs reflects the urgent need for flexibility, which was not present in using proceed instruments such as green bonds. In other words, SLBs enable entities to use the funds comprehensively instead of compromising in using the funds in just one project classifies as green or sustainable. Lastly, we must assume that all sectors in the economy should be engaged

[27] International Capital Market Association (ICMA), *Sustainable Finance High-level definitions*, May 2020.

[28] ICMA, *Climate Transition Finance Handbook*…, cit.

with the race towards net-zero. In order to align efforts from all range of economic activities, SLBs give access to capital to hard-to-abate sectors that still require resources to pursue decarbonisation strategies.

One of the main priorities of transition finance is to reduce greenwashing practices. Consequently, there are constant efforts to improve the definitions and requirements of sustainable financial instruments linked with the recent concept. Following Caldecott (2020),[29] transition finance instruments, such as SLBs, should align their targets to the UN SDGs and the Paris Agreement. In the first place, because anything less ambitious than that cannot be as helpful as expected and, in second place, there are interrelationships to consider.

Green bonds and SLBs can be related to both the Paris Agreement and SDGs, as they require science-based targets based on the 2°C scenario and ambitious strategies to incorporate social and economic dimensions. The innovative perspective of SLBs allows issuers to develop more comprehensive strategies, facilitating additional ESG dimensions and aligning with the broader perspective of the UN SDGs. By being linked to results rather than qualified projects that may or may not lead to significant impacts, SLBs offer more reliable sustainable investment from environmental and financial perspectives. Nevertheless, due to their complexity, the SLBs are not suitable for all types of entities, projects, or investors. For this reason, green bonds will maintain an essential role in the transition financial markets.

How can the greenness of infrastructure bonds be improved from a transition finance approach? Caldecott (2021)[30] sheds new light on what should be considered green. In this regard, financial instruments must meet at least two conditions. The first one is the capacity to encourage green activities and inhibit brown ones. In this context, green bonds and SLBs are

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[29] B. Caldecott (2020).

[30] B. Caldecott, "Viewpoint: Investing in green doesn't equal greening the world", IPE, 10 February 2021.

complementary mechanisms to finance assets that genuinely contribute to a sustainable transition. On the one hand, green bonds support specific projects that are already green, like solar energy production. On the other hand, SLBs allow companies not yet sustainable to follow an ambitious decarbonisation pathway contributing to the upcoming net-zero economy. For instance, natural gas companies can explore pipeline innovations that can be used for the future green hydrogen economy.[31] This is an interesting example of how hard-to-abate sectors should analyse different areas of their value chain to engage with a credible transition.

The second condition states that the financial product must make a clear and measurable difference in one or more of the following factors: A) cost of capital, B) liquidity, C) risk management, D) corporate sustainability strategies, and E) spill-over effects. The former two are the most relevant since they directly affect the availability and cost of capital for green and brown projects.

There is no solid evidence suggesting green bonds comply with factors A and B, because they do not include borrowing costs incentives, and the nature of a fixed-income instrument inhibits liquidity. However, green infrastructure bonds effectively address risk management where the repayment obligations are linked with the infrastructure project via a particular purpose vehicle. Moreover, green bonds can contribute to D and E since the process of monitoring and reporting the proceeds gives additional sustainable benefits because it highlights issuers' green assets and business.[32]

In contrast, SLBs directly address the cost of capital, subjecting the interest rates to sustainability performance targets. Furthermore, well-designed SBLs that follow ICMA principles can incentivise a green activity and disincentivise brown ones, fully linking the financial stimulus to sustainable

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[31] C. Findlay, "What's your purpose? Reusing gas infrastructure for hydrogen transportation", Siemens Energy, 11 September 2020.

[32] Amundi Research (2020).

performance. They also promote sustainable practices throughout the company's activities because they do not label the expense. In a nutshell, SLBs address almost all the factors of the second condition, except for the liquidity aspect, and have the potential to make greater contributions to the rest of the factors to which green bonds potentially contribute. For instance, corporate sustainability strategies are directly considered in the SLBs instruments through the sustainability performance targets of the corporation, while green bonds do not necessarily contribute to this aspect because they are not considered in the instrument mechanism.

In addition, it is necessary to ask if the issuer would achieve the goal despite the participation of sustainable markets. ICMA also addresses that issue, insisting on having a well-justified and scientific-based benchmark. Green bonds and SLBs issuers must establish targets that differ from the business-as-usual path. Nevertheless, green bonds and SLBs still must prove themselves indispensable to make a change occur that would not otherwise happen. Benchmarking SPTs and KPIs against relevant industry and sector standards is essential and has a scientific basis for affirming that the company's actions are contributing to sustainability rather than just following unstoppable trends. However, this is not a problem exclusive to these instruments but a challenge for the sustainable finance field.

A very well-constructed example of implementing an SLB following ICMA principles and Caldecott's recommendations is ENEL, which has adopted a strategy around the SDGs with environmental sustainability as its core. ENEL has its framework for the issuance of sustainable linked instruments.[33] They are planning to invest €11.8 billion in infrastructure, mainly on-grid digitalisation. ENEL managed more than 2.2 million kilometres of smart grid in eight countries. Intelligent and digital electric grids are critical to the net-zero transition, as they allow renewable energies to connect to the network and

[33] ENEL, *Sustainability-Linked Financing Framework*, January 2021.

reach consumers reliably and efficiently. The interest rates are adjustable depending on the performance of ENEL in the two selected KPIs: direct greenhouse gas emissions amount and renewable installed capacity percentage. Failing in achieving its KPIs goals would lead to an increase in the interest rate applicable to interest periods following such reference date.

Conclusion

The key to a successful transition lies in the capital replacement puzzle. In order to reallocate capital towards low carbon assets will need an ultimate market driver: the repricing of the capital stock. The pace at which the current capital market value falls will decide whether we can reverse climate change or not. By the time the new capital market value rises, investment in the old one will halt, and its cash flow will be directed to the assets aligned to a net-zero economy. However, those resources will not be sufficient. Thus, capital markets will play a key role, mainly through sustainable debt instruments such as green bonds and sustainability-linked bonds.

There are promising signs to support the belief that the sustainable market will continue growing: the long-awaited European Union taxonomy is well advanced, the prices of renewable energy and sustainable technology are falling, the United States has announced a vast sustainable plan for recovery, and there is a growing citizen demand for climate action. We can expect to improve metrics and targets aligned with climate science for low-carbon climate-resilient infrastructure as a critical asset class to transition towards net-zero. It is clear that investors still face uncertainty about the sectorial decarbonisation pathways in different regions. However, we can expect better government guidance after the growing wave of net-zero pledges during the pandemic.

EU TAXONOMY: WHAT NEXT?

Antongiulio Marin

The European Green Deal establishes a clear direction for a comprehensive policy framework for transforming the EU economy and putting sustainable finance at the heart of the financial system. The EU Green Taxonomy[1] plays a crucial role in programming public funding as well as in mobilising private investment. Against this background, the "Sustainable and Smart Mobility Strategy" supports the green and digital transformation of the EU transport system and makes it more resilient to future crises.

The European Green Deal calls for a radical reduction in greenhouse gas emissions from transport, energy supplies, networks and industries, and for the EU to develop a climate-neutral economy by 2050. This, however, will require rapid deployment of new technologies in combination with greater investment, particularly from the private sector, in sustainable energy, transport, housing and industrial infrastructures. Such a transformation could have a major impact on mobility, considering for instance the external environmental costs of transport, including congestion and accidents.

The EU Taxonomy Regulation, approved in June 2020, empowers the Commission to adopt Delegated Acts specifying technical criteria and thresholds for identifying economic activities that "substantially contribute" to an environmental objective, but "do no significant harm" (DNSH) to other environmental objectives. The Delegated Act defining the technical criteria for activities that substantially contribute to climate change mitigation and adaptation objectives was adopted on 21 April 2021[2] following extensive public consultation, with over 200 replies received from the transport sector industry and input from Member States. The Communication on "*EU Taxonomy, Corporate Sustainability Reporting, Sustainability Preferences and*

[1] Regulation (EU) 2020/852 (Taxonomy).

[2] European Commission, Financial Stability, Financial Services and Capital Markets Union, "Sustainable finance package", 21 April 2021.

Fiduciary Duties: Directing finance towards the European Green Deal" was published the same day.

The Commission's assessment of the Green Deal identifies investment needs estimated at €130 billion per annum over the period 2021-30, in vehicles (including rolling stock), renewable and low carbon fuels and infrastructure. The "green and digital transformation investment gap" for transport infrastructure would require an additional €100 billion per year. Green bonds can contribute to bridging this gap.

The EU is already indirectly and directly mobilising additional public investment to help unlock private funds for the deployment of alternative fuels. Under the Multiannual Financial Framework for 2021-27, Member States can support the deployment of sustainable infrastructure through a wide range of complementary but differently focused financing instruments. The Recovery and Resilience Facility also supports investment in sustainable infrastructure and future-proof clean technologies to accelerate the use of sustainable, accessible and smart transport, including charging and refuelling stations and the expansion of public transport. A large majority of Member States are already considering the inclusion of investments and reforms that contribute to sustainable and smart mobility in their national plans.

A greener, carbon-neutral Europe will be at the heart of Regional Development Fund investments. In implementing the Paris Agreement, investing in energy transition and renewables, and combatting climate change, regions in receipt of ERDF and Cohesion Fund support will benefit from the programme's prioritisation of "greening".

The Connecting Europe Facility programme likewise aims to accelerate investment in the field of trans-European networks through funding from the public and private sectors, thereby contributing to the timely and efficient development of the TEN-T Network while supporting the realisation of a robust and resource-efficient European transport system. In complete accordance with the European Green Deal, CEF 2021-27 will address climate change and contribute 60% of its overall financial envelope to co-financing actions in support of climate objectives and rapid progress towards zero-emission mobility.

Finally, under the Horizon Europe programme, new EU Missions will be established to orchestrate innovative solutions to key societal challenges, including climate change. The proposed Mission on Climate Neutral and Smart Cities aims at making 100 cities climate neutral by 2030. Stimulating urban transport and mobility will be key to the success of this Mission, which will offer opportunities for cities seeking to invest in clean public transport.

Unfortunately, public spending – even if supplemented by private investment – will not be sufficient to address all financial needs. InvestEU, however, mainly through its “Sustainable Infrastructure Window”, can bolster future-oriented investment across the European Union, help mobilise private investments by providing advisory services to projects and operators in the area of sustainable infrastructure and mobile assets, and support innovative companies and SMEs in the areas of smart and sustainable mobility.

Further, in recent years, the EIB Group has been ramping up its support to accelerate newer technologies such as e-mobility and digitalisation under the flag of the Cleaner Transport Facility.[3] The EIB Group will continue to deploy a range of finance structures to accelerate the deployment of cleaner mobile assets.

The Sustainable and Smart Mobility Strategy highlights how investments in transport sector renewal should be accompanied by business investments in more sustainable and digital mobility. Technical screening criteria based on the Taxonomy Regulation will be defined for all transport modes, recognising specific investment needs and taking account of existing technologies. In this context, the financing of sustainable transport investments could build on the upcoming European Green Bonds Standard anchored on the EU Taxonomy. The Sustainable Smart Mobility Strategy also promotes transport investment based on a new EU infrastructure asset class that could cover infrastructure projects associated with European

[3] European Investment Bank, “The Cleaner Transport Facility”.

strategic planning, such as the TEN-T projects. According to reports by the Climate Bond Initiative, transport represents about a quarter of the green bond market, matching energy and the building sector. The European rail industry certainly ranked among the top green bond issuers in terms of total value. Broadly speaking, such green securitisation can free resources for reinvestment in sustainable assets. Infrastructure project bonds are another underdeveloped but flexible and attractive vehicle to serve the priorities of the European Green Deal and to unlock additional private finance.

Investment in infrastructure – including technology-driven solutions aimed at meeting the objectives of the Green Deal – is generally considered an "alternative investment" by institutional investors, and therefore accounts for only a small fraction of their overall investment strategy. Commercial and promotional banks could indeed provide substantial support to the infrastructure sector. However, though the risk profile of sustainable infrastructure investment, demonstrator and novel technology deployment matches the requirements of long-term investors, due diligence for such projects is complex and regulatory risks are often high. This deters institutional investors from engaging more actively with the sector. In some cases, private investors also lack the expertise to apply due diligence to infrastructure projects and prefer to invest in other financial assets, such as treasury bonds or shares, which are easier to assess and more liquid. More broadly, lack of strategic planning and poor project preparation, asymmetric information on novel technologies, poor business cases and barriers (state infrastructure ownership and lack of competition) also prevent investors from engaging further in project financing.

Scaling up the project green bond market for sustainable infrastructure, buildings, renewable energy, demonstrator and novel technology deployment is one answer to the growing demand for green assets and could be promoted using public guarantees from Member States or from the Union's budget, such as InvestEU. Bond credit and subordinated debt financing in particular could enhance the use of green bonds and securitisation for sustainable infrastructure.

Increased investment in sustainable infrastructure, through green corporate and project bonds, would offer investors increased financing and liquidity for infrastructure-linked assets, alternative investment-grade securities, and the ability to diversify portfolios into infrastructure assets even without the capacity to oversee infrastructure due diligence. It would also offer banks, building societies and specialist lenders the opportunity to re-finance loan portfolios to include multiple smaller sustainable infrastructure investments.

The solutions proposed above would boost use of the Taxonomy itself and promote the EU Green Bond Standard for investments in compliance with the provisions of the Green Taxonomy Regulation and the Delegated Regulation.

The international dimension of sustainable finance also needs to be enhanced. The G20 Infrastructure Working Group (IWG), for instance, has recognised the benefits of promoting infrastructure as an asset class to improve the investment environment and mobilise higher levels of investment through capital markets.[4] Notably, under the Italian G20 Presidency on April 7, the G20 Finance Ministers and Central Bank Governors welcomed the re-establishment of the Sustainable Finance Study Group and agreed to elevate it to working group status.

To move forward while considering stakeholder feedback, it is clear that markets need other tools than the Green Taxonomy to facilitate the transition of economic actors towards sustainability, a key issue for the Platform on Sustainable Finance.[5] With this in mind, the European Commission published on 6 July the Sustainable Finance Package,[6] comprising the Strategy for Financing the Transition to a Sustainable Economy and the proposal for a Regulation on European Green Bonds.

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[4] G20/OECD Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure: Investor Proposals and the Way Forward, OECD, 2020.

[5] G20/OECD Report on the Collaboration..., 2020.

[6] European Commission, "Strategy for financing the transition to a sustainable economy", Financial Stability, Financial Services and Capital Markets Union Banking and financial services, 6 July 2021.

4. The Future of Renewables for the Energy Transition

Francesco La Camera

Renewable electricity generation is a key pillar of energy transition. By 2050, demand for electricity will expand three-fold, largely because of the rapid electrification of end-uses such as transport and green hydrogen, and renewables could provide as much as 90% of this.

As outlined in the 1.5°C Scenario of IRENA's (International Renewable Energy Agency) *World Energy Transitions Outlook*, wind and solar photovoltaic (PV) generation can meet the bulk of this demand by mid-century, providing 63% of our electricity, supported by other mature renewable technologies such as hydropower, geothermal, concentrated solar power (CSP) and bio-energy.

Over the course of its lifetime, around three-quarters of current onshore wind capacity will produce cheaper electricity than any fossil-fuel alternative. The same applies to 40% of utility-scale solar PV commissioned in 2019, while as much as 80% of onshore wind and utility-scale solar PV commissioned in 2020 from auctions and tenders already offers lower prices than the cheapest new fossil fuel-fired option.

However, this improving business case for renewables must be coupled with supportive policies and regulatory frameworks if we are to ensure growth in installed renewable capacity from over 2500 GW today[1] to more than 27,700 GW in 2050. This

[1] IRENA, *Data and statistics*, www.irena.org/Statistics.

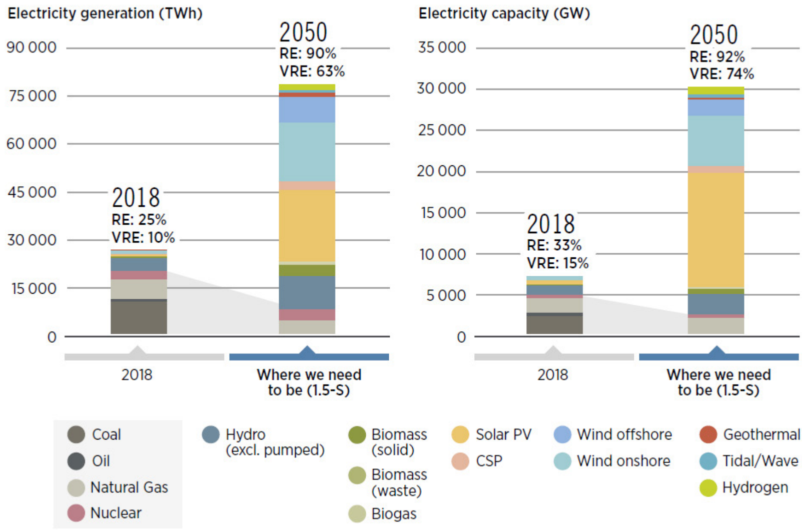
means more than 840 GW of new renewable capacity each year, far more than the record 260 GW added in 2020.

Solar PV and wind power could lead the way, with installed capacities of over 14,000 GW and 8,100 GW respectively by 2050. Hydropower, biomass, geothermal, CSP and emerging ocean energy technologies can account for the remaining renewable energy expansion. Solar thermal, geothermal and bioenergy will also be needed to provide heat in industrial processes, cooking and water heating in buildings, as well as in fuels for transport.

Bioenergy will remain a significant source of fuel both in industry and transport. In the 1.5°C Scenario, modern forms of bioenergy will account for 17% of our energy by 2050, up from around 1.5% today. Priorities for bioenergy include the production of advanced biofuels for the aviation and shipping sectors, as well as fuels and feedstock for the chemical industry.

Bioenergy coupled with carbon capture and sequestration (BECCS) will be used in power and heat production and in some industrial processes (e.g. cement production). While the primary biomass required for this expansion can be harvested sustainably, robust frameworks for regulation, certification and monitoring will be needed.

Fig. 4.1 - Renewables dominate the power generation mix in the 1.5°C Scenario

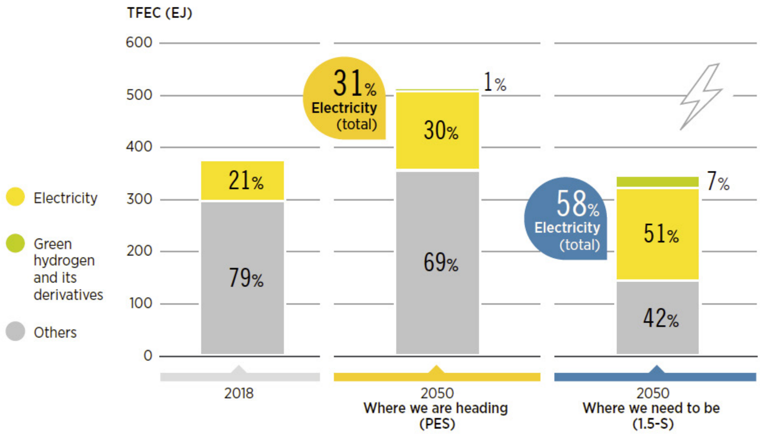


Note: 1.5-S = 1.5°C Scenario; CSP = concentrated solar power; GW/yr = gigawatts per year; PES = Planned Energy Scenario; PV = photovoltaic; RE = renewable energy; TWh/yr = terawatt hours per year; VRE = variable renewable energy.

Source: IRENA, 2021

Direct electricity use will rise from around 21% of energy use today to over 50% in 2050, while green hydrogen and its other fuel products (such as e-ammonia and e-methanol) will account for around 7%. In total, direct and indirect electrification will satisfy 58% of final demand by mid-century.

FIG. 4.2 - ELECTRICITY IS THE CENTRAL ENERGY CARRIER OF THE FUTURE ENERGY SYSTEM



Note: "7%" in 2050 in the 1.5°C Scenario (1.5-S) corresponds to green hydrogen and its derivatives. In addition, around 11 EJ of green hydrogen would be needed for non-energy uses in 2050 (1.5-S), which is not represented in this figure.
EJ = exajoules; PES = Planned Energy Scenario.

Source: IRENA, 2021

In the 1.5°C Scenario, electricity plays an increasingly central role across all sectors of the energy system. The buildings sector will see the highest direct electrification rates, reaching 73% compared to 32% today, whilst direct electrification in industry will rise to 35% by 2050 (40% including indirect electrification) from 26% today. The total number of heat pumps for decarbonisation will exceed 180 million by 2030 and reach close to 400 million by 2050, compared to around 20 million installed today.

The transport sector will see the most accelerated electrification in the coming decades, reaching a 49% share in 2050, up from just 1% today. The stock of electric cars will rise from 10 million to over 380 million by 2030 and 1780 million by 2050, while electric trucks will rise to 28 million by 2050. In the 1.5°C Scenario, electric vehicles (EVs) will account for more than 80% of all road transport activity by 2050.

This massive electrification in transport will be supported by technological progress such as the evolution of batteries, which has greatly improved the economic case for EVs in recent years and is quickly expanding the scope of applications to a broader set of road vehicle segments. If cost reduction trends can be sustained, the bulk of global road transport services could be delivered cost-effectively with electric technologies by 2050.

Importantly, in a Paris Agreement-compliant 2050 energy system, there is no place for coal. Coal generation falls to a quarter of today's level by 2040 and is phased out entirely by 2050. The remaining 10% of global power not supplied by renewables will be met by a combination of natural gas (around 6%) and nuclear (around 4%).

Increasing Flexibility

Flexibility in power systems is a key enabler for integrating high shares of variable renewable energy (VRE) – the backbone of the electricity system of the future. In IRENA's 1.5°C Scenario, VRE will account for 42% of total power generation by 2030; by 2050, 73% of installed capacity and 63% of all power generation will come from VRE (notably solar PV and wind), up from 15% of installed capacity and 7% of power generation today. This can be achieved with the support of systemic innovations in business models, markets, regulations and system operations to unlock flexibility in the power system and integrate rising shares of VRE.

IRENA has identified 30 flexibility options that can be combined into comprehensive solutions, taking into account national and regional power system specifics.[2,3] The Agency has also analysed how power system organisational structures (including markets) can be redesigned to support

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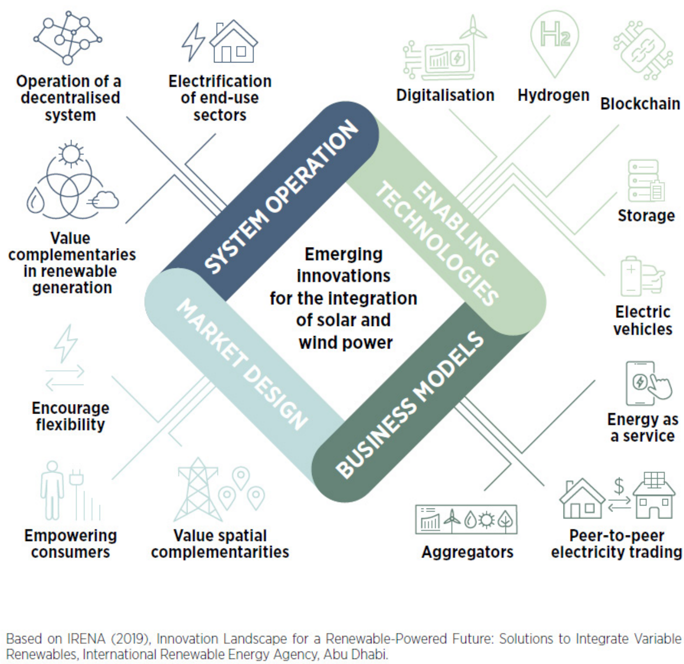
2 International Renewable Energy Agency (IRENA), *Innovation landscape for a renewable powered future: Solutions to integrate variable renewables*, Abu Dhabi, 2019.

3 IRENA, Innovation toolbox, 2020.

renewable-based energy systems.[4] As more countries adopt ambitious renewable energy targets, such a systemic approach to innovation will become more important.

A future smart power system, largely based on variable renewables such as solar PV and wind, will require the investment in power grids and flexibility measures (e.g. storage) of some US$730 billion per year over the period to 2050, nearly triple the US$275 billion spent in 2019.[5]

FIG. 4.3 - EMERGING INNOVATIONS FOR THE INTEGRATION OF VRE



Source: IRENA, 2021

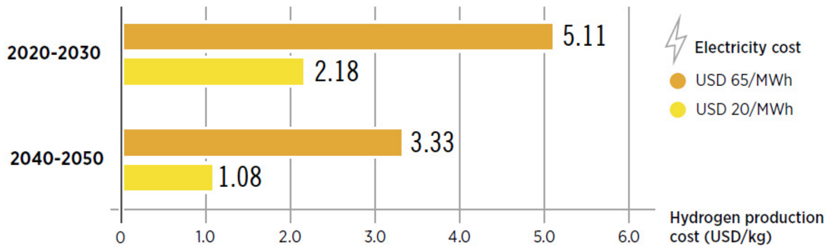
[4] International Renewable Energy Agency (IRENA) (2020), *Power system organisational structures for the renewable energy era*, Abu Dhabi, 2020.

[5] International Agency (IEA), *World Energy Investments 2020*, Flagship Report, Paris, 2020.

Greening the Gas Grid

By 2050, 30% of electricity use will be dedicated to green hydrogen production and derivatives such as e-ammonia and e-methanol. Solutions are needed to carry renewable energy to sectors that cannot be electrified, particularly within the 65% of industry and 30% of transport that make up hard-to-decarbonise-sectors (HTDS). Hydrogen and its derivatives will account for around 12% of total final energy use. To produce this, almost 5,000 GW of hydrogen electrolyser capacity will be needed by 2050, up from just 0.3 GW today.

Fig. 4.4 - The falling cost of green hydrogen production



Note: A combination of cost reductions in electricity and electrolysers, combined with increased efficiency and operating lifetime, can deliver 80% reduction in green hydrogen cost.

Based on IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal, International Renewable Energy Agency, Abu Dhabi.

Source: IRENA, 2021

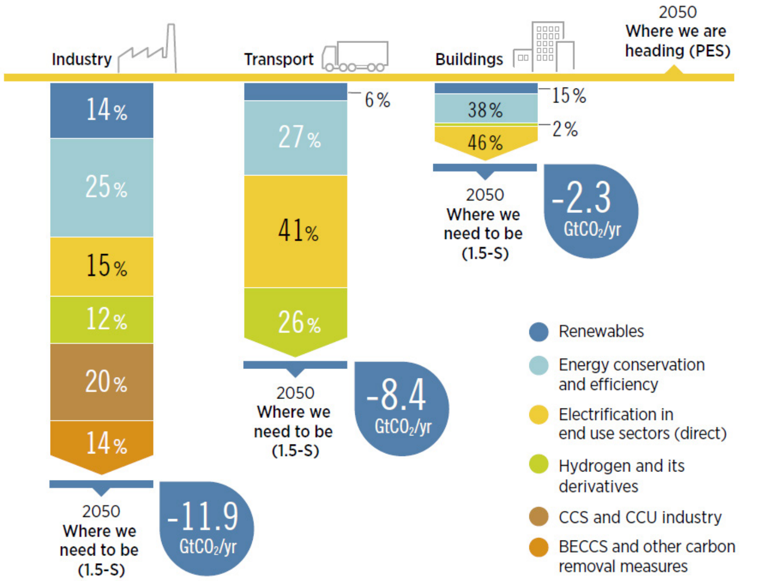
Green hydrogen is produced using renewable power to operate an electrolysis unit that splits water into its constituent elements – hydrogen and oxygen. Hydrogen emits only water upon combustion and can be transported as a gas or liquid and stored in large quantities. It can be transported by ship between continents or sent by pipeline to consumers in large quantities over thousands of kilometres and with minimal energy loss. Green hydrogen is therefore an ideal zero-carbon energy carrier that can be used as fuel for power and heat in industry and transport, as well as feedstock for the e-fuel and chemical industries.

Other methods of using renewables to produce green hydrogen exist but have not been developed on a commercial scale. There are also methods of producing hydrogen without the use of renewables – the cleanest of which is "blue hydrogen", produced by splitting natural gas and employing CCS to capture most of the CO_2 that is produced. Nonetheless, green hydrogen is the only zero-carbon hydrogen product.

Hydrogen will offer a solution to industry and transport needs that are hard to meet through direct electrification, mitigating close to 12% and 26% of CO_2 emissions from both sectors respectively in IRENA's 1.5°C Scenario, which foresees a demand for 613 Mt of hydrogen, two-thirds of which will be green.

The electricity required to produce hydrogen will reach close to 21,000 TWh by 2050, almost equal to global electricity consumption today. This will require a significant scale-up of electrolyser manufacturing and deployment, with around 160 GW of electrolysers installed annually to 2050.

Fig. 4.5 - Electrification and green hydrogen in CO_2 emissions abatement



Note: Industry includes emissions from energy, process and non-energy uses. International bunkers are included in transport emissions. Renewables include direct use of renewables such as biomass, solar thermal and geothermal. Energy efficiency includes measures related to reduced demand and efficiency improvements. Structural changes (e.g. relocation of steel production with direct reduced iron) and circular economy practices are part of energy efficiency. Electrification includes direct use of clean electricity. Hydrogen includes indirect use of clean electricity via synthetic fuels and feedstocks (e.g. hydrogen and its derivates). CCS describes carbon capture and storage from point-source fossil-fuel-based and other emitting processes mainly in industry and for blue hydrogen production. BECCS and other carbon removal measures include bioenergy coupled with CCS (BECCS) and other measures such as reforestation and other measures in industry.

$GtCO_2$ = gigatonnes of carbon dioxide;

Source: IRENA, 2021

In transport, 67% of emission reductions will come from direct electrification and hydrogen. In industry, hydrogen and electricity combined represent 27% of mitigation needs. In buildings, the key solution is electrification (direct and indirect), which will contribute close to half of the reduction needed, followed by energy efficiency.

Green hydrogen also offers solutions to challenges such as energy storage, capturing excess renewable energy from wind and solar, addressing the intermittent delivery of electricity from VRE sources, and reducing energy losses over long distances. With the aid of a large, complementary gas-based storage system, hydrogen can be extracted to balance gaps in electricity, from hourly to seasonal timeframes. The potential is significant; for example, existing gas storage units across Europe could hold 1,131 TWh, representing 21% of Europe's annual gas consumption.[6]

To effectively address climate change in the energy sector, we must introduce the maximum amount of renewable energy possible, while also phasing out fossil fuels. This needs to be achieved in the most "system efficient" way, taking into account the overall cost, disruption to people and the environment, reduction of emissions, and both the reliability and security of our energy supplies. The most system efficient means to deliver renewable energy from A to B should be assessed and developed – be it electricity, hydrogen or a mix of the two.

Investment Needs

Government plans in place today call for almost US$98 trillion of investment in energy systems over the coming three decades. Economic stimulus packages announced so far will direct US$4.6 trillion into sectors that can have a large and lasting impact on carbon emissions – namely agriculture, industry, waste, energy and transport – of which less than US$1.8 trillion is green.[7]

To ensure a sustainable, climate-safe and resilient future, significant investments need to flow into building an energy system that prioritises renewables, electrification, efficiency and associated energy infrastructure. However, those investments must not lead to lock-in effects that are incompatible with IRENA's 1.5°C Scenario. This could be achieved by adding

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[6] GSE.

[7] Vivideconomics and Finance for Biodiversity Initiative, *Greenness of stimulus: Index*, January 2021.

US$33 trillion to planned investments to reach US$131 trillion up to 2050, as shown in Figure 4.6. Over 80% (US$116 trillion for the period to 2050 or around US$4 trillion per year) must be invested in energy transition technologies (excluding fossil fuels and nuclear) such as renewables, energy efficiency, end-use electrification, power grids, flexibility innovation (e.g. hydrogen) and carbon removal measures.

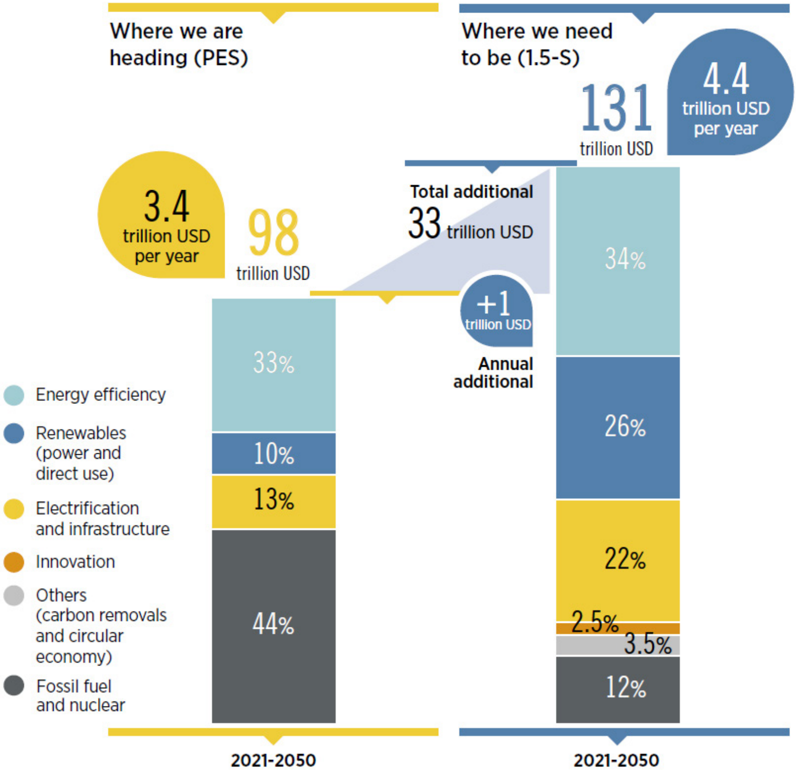
The 1.5°C Scenario also shows that cumulative investments of over US$24 trillion should be redirected from fossil fuels to energy transition technologies over the period to 2050. In annual terms, energy sector investments of US$4.4 trillion per year until 2050 would be needed, well over the US$1.8 trillion invested in 2019.[8] Compared to IRENA's Planned Energy Scenario (PES),[9] US$1.1 trillion in additional energy sector investments would be needed in the next three decades.

In the more immediate term to 2030, cumulative investments in the energy system – including infrastructure and efficiency – would reach US$57 trillion. In addition to money for research and development, equipment and infrastructure, investments in people are also needed, in the form of training and reskilling, labour market programmes, economic development and social protection measures.

[8] IRENA, *Power system organisational structures for the renewable energy era*, International Renewable energy Agency, Abu Dhabi, 2020.

[9] The Planned Energy Scenario (PES) is the primary reference case for this study, providing a perspective on energy system developments based on governments' current energy plans and other planned targets and policies (as of 2019), including Nationally Determined Contributions (NDCs) under the Paris Agreement.

FIG. 4.6 - NEW INVESTMENT PRIORITIES IN THE PES AND 1.5°C SCENARIO



Source: IRENA, 2021

To deliver electrification at scale, investment will clearly be needed to build or upgrade key infrastructure. This includes electricity and hydrogen production, energy transmission and distribution networks, and end-user infrastructure.

The time for action is now. We must capitalise on the investment momentum in the wake of the Covid-19 pandemic to rebuild our economies in a way that is supportive of a green future. The 1.5°C Pathway begins here, with public investment being channelled away from fossil fuels and towards energy transition, including the enabling infrastructure required for the efficient use of renewable power.

Energy industry bailouts and financial support to carbon-intensive companies should be made conditional on measurable climate action. Comprehensive, supportive and clear policy frameworks should also be leveraged to mobilise energy transition-related investment. Important government actions should include: risk mitigation instruments (e.g. guarantees, currency hedging instruments and liquidity reserve facilities) to attract and de-risk private capital; pipelines of bankable renewable energy projects; sustainability requirements for investors (e.g. climate risk analysis and disclosure); reviewed investment restrictions and sustainability mandates for institutional investors; and standards for green bonds that reflect global climate objectives.

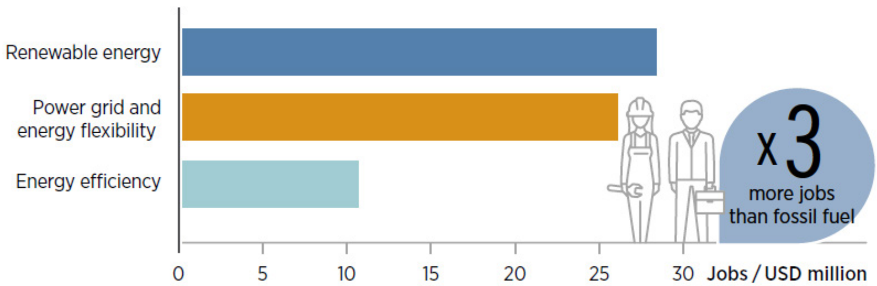
Moreover, carbon pricing should be implemented, where possible, to avoid distorted economic uptake as the pandemic recedes. Of course, careful consideration of broader social and equity issues is necessary, particularly for low-income populations for whom energy constitutes a larger share of household expenditures and whose budgets do not leave many options.

Socio-Economic Implications

The transition will provide jobs in renewable energy, energy efficiency, electrification and green fuels. Globally, employment in the 1.5°C Scenario follows a higher growth path than under current plans. Overall welfare gains are even higher because they comprise improved health, reduced pollution and better incomes. To fully reap these potential benefits, however, distributional aspects need to be addressed and included in policy action from the outset.

In the energy sector, energy transition brings both positive and negative employment effects. On the positive side, new jobs are created in renewables, energy efficiency and system flexibility. Investing in energy transition technologies creates close to three times more jobs than fossil fuels do for each million dollars of spending; but it necessarily entails the phase-out of fossil fuels, which represent a significant share of energy sector employment. At the global level, the employment balance is positive, with the 1.5°C Scenario providing an increase in total energy sector jobs over current plans.

Fig. 4.7 - Employment intensities of transition-related technologies



Source: IRENA, 2021

New jobs created by energy transition also include those in academia and research, as well as the testing, manufacture, installation, operation and maintenance of renewable energy technologies. Other sectoral and economy-wide transition dynamics are sure to affect the evolution of employment in the broader energy sector.

Job outcomes for individual countries or regions depend not only on their readiness for incorporating renewables, but also on their economic structures, the skills and capacities they can marshal, and the degree to which these resources can be aligned with the challenges and opportunities brought about by the transition. To ensure that an expanding renewable energy workforce possesses the right knowledge and skillsets therefore requires appropriate education and training programmes, re-training and social protection, co-ordination between industry and educational entities, and active labour market measures.

5. The Role of Natural Gas: A Transitional Source of Energy?

Giacomo Luciani

The share of natural gas in total primary energy sources (TPES) has been growing constantly and rapidly over the past half century and more. Yet some scenarios about the future of global energy predict a decline, in some cases slow, in other cases strikingly rapid. The fork of expectations about the future of gas is considerably wider than for almost all other primary energy sources: the role of coal has been declining for a century (as share of TPES, not at all in absolute volumes), the role of oil since the early 1970s, the role of renewables is growing rapidly: while different views exist on the speed of these processes, their direction is not in doubt.

According to the International Energy Agency, the share of natural gas in the global energy mix has remained rather stable in the last two decades, around 20%[1] of global energy supply. In 2018, gas saw a significant increase in consumption,[2] largely due to the shale developments in the US and to China's increasing concerns for air pollution, which prompted a switch from coal to gas. While a decline in 2020 can be expected due to high temperatures and reduced economic activities during the

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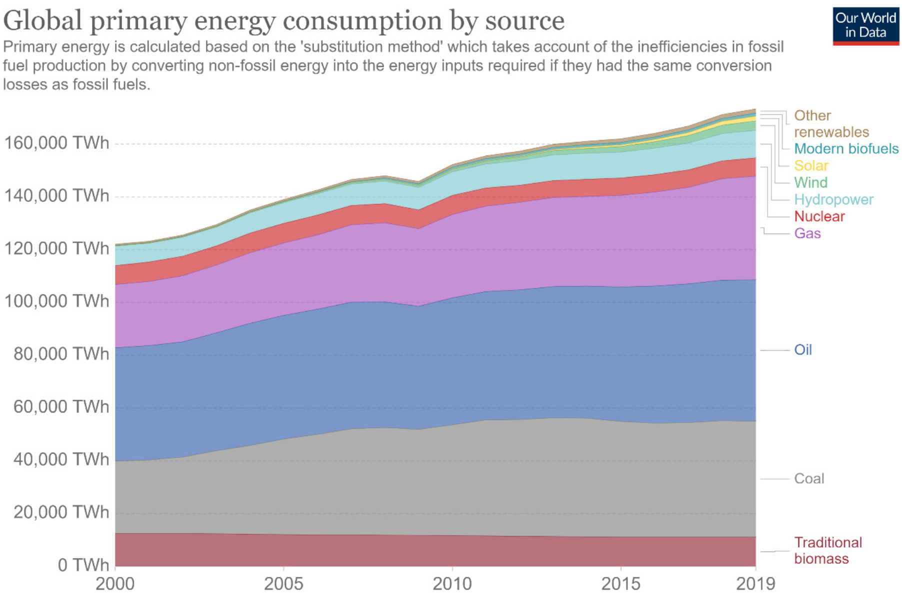
[1] Data and Statistics, International Energy Agency (IEA), https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=Energy%20supply&indicator=TPESbySource.

[2] Gas, International Energy Agency (IEA), https://www.iea.org/fuels-and-technologies/gas.

pandemic, the strong push for a sustainable recovery in both the US and the EU can sustain a greater role for natural gas as an energy source. The pattern of gas consumption, however, is extremely varied depending on economic sector: while it accounts for a relevant share of total energy in power generation, industry and buildings, its role in the transportation sector remains negligible. In 2019, gas was responsible, on a global scale, for only 7.5 billion tons of CO_2 emissions while coal and oil accounted for 14.4 and 12.4 billion tons respectively.[3]

FIG. 5.1 – GLOBAL ENERGY MIX, 2000-2019



Source: V. Smil (2017) and BP Statistical Review of World Energy

There are structural reasons for the uncertainty surrounding gas. Methane is a very versatile source of energy and has some

[3] H. Ritchie and M. Roser, "CO_2 emissions by fuel", *Our World in Data*.

significant advantages, but is neither necessary nor dominant in any of the final uses of energy. While oil is dominant in mobility uses, and coal in global power generation, gas always is second or third, not indispensable for any specific use. Gas is always a competitor in all sectors: against oil, coal, renewables or electricity.

This means that generally our expectations of the future of gas are shaped by expectations about the future of other sources: gas is the N-1 source, that whose share is defined by subtracting from 100 the sum of the expected shares of all other sources. As such, it displays the greatest uncertainty.

While being considerably "cleaner" than other sources (gas generates half the amount of CO_2 that coal does) methane is itself a potent greenhouse gas (GHG), and concern about methane emissions (mostly from biological sources, but also from the production of coal, oil and natural gas, plus the transport and distribution of the latter) has been growing. Hence the conclusion that eventually the world will need to stop extracting fossil methane from the ground (but maybe using more of the methane produced from biological sources); therefore, gas can at most be viewed as a transitional energy source. What transitional exactly means remains an open question: *panta rei*, all reality is transitional and bound to change, but the transition may be very long or very short. In economic and investment terms, the relevant time horizon is three decades (2050), as anything that may be produced or earned beyond such a date has in almost all cases minimal or zero present value, in addition to being certainly impossible to predict.

In discussing the future role of gas, one could take the easy option of taking cover behind one of the several scenarios put forward by various sources, for example the International Energy Agency (IEA) and their STEP (Stated Energy Policies Scenario) SDS (Sustainable Development Scenario) or even the very recent NZE (Net-Zero Emissions by 2050 Scenario), but I am afraid this would leave the reader with an incomplete understanding of the issues underlying the divergent views. Thus, this paper will discuss the role of gas as a function of the expected or possible role of all remaining energy sources, so that the reader should ultimately be able to make up their own mind about the future of gas and the speed of the transition, rather than just relying on the black box generating a scenario.

The Future of Carbon Capture and Sequestration

The first open issue affecting the future role of natural gas is the extent to which the world may rely on carbon capture and sequestration (CCS). Views on the future of CCS diverge rather radically: current levels of implementation are low, although this is a solution that has been considered for a long time. The technology behind it is well proven but the costs are high. Sceptics view CCS as a fake and unreliable solution promoted by fossil fuel industries so that they might be able to continue extracting and using fossil fuels. At the same time, several large (primarily oil and gas) companies have announced major projects and are lobbying for a higher carbon price to make CCS commercially viable. The IEA believes that CCS is an unavoidable component of any deep decarbonisation effort.

CCS is important for the future of natural gas because it opens the possibility of using methane while capturing the resulting CO_2. It is easier to capture CO_2 from methane rather than other fossil fuels (especially coal) in large-scale fixed uses (primarily power generation). Therefore, the continuing use of methane, especially in power generation in a decarbonised world, is conditional on the implementation of CCS.

CCS is also important in allowing the transformation of methane into low carbon or "blue" hydrogen. The possibility of producing reasonably priced hydrogen in large enough quantities in the next three decades is conditional on the use of methane reforming with CCS and blue hydrogen production (more on this later).

Large-scale CCS may also to some extent allow for slower decline in the use of coal in power generation; as such, it also somewhat benefits coal in the competition with gas, but benefits gas more.

The Future of Coal

Coal and gas compete primarily in power generation. So far, the competition has revolved around cost and flexibility. Depending on the country and location of a power plant, coal may be cheaper than gas or vice-versa. In locations in which both solutions are possible, the share of electricity produced from coal or gas varies depending on the relative price of the two fuels.

Flexibility is important because it is needed to accommodate the variations in electricity demand as well as, increasingly, in the availability of non-dispatchable renewable resources such as wind and solar. Coal power plants are generally large and operationally not flexible, and are hence preferred for providing base load; gas power plants are smaller and more modular, plus they can operate very flexibly, so are preferred for meeting intermediate and peak load.

From the point of view of emissions, coal, as mentioned, is on average twice as harmful as gas: therefore, reducing the share of power generated from coal and increasing the share of gas allows for an immediate and easy reduction of emissions. The bulk of the reduction in emissions in the United States has been achieved through switching from coal to gas in power generation; conversely, one of the reasons that the outcome of the *Energiewende* in Germany has been so disappointing, is that coal has prevailed in the competition with gas.

Gas's competitiveness against coal depends on the level of a carbon price that may (or may not) be imposed, and on the cost of transportation, which is much higher for gas than for coal. That said, even countries that have ambitious decarbonisation targets and no domestic sources of either gas or coal, such as Japan, envisage continued use of the latter.

Use of coal will certainly decline, but the decline may be slow. Even in Germany, the use of coal in power generation is not expected to end before 2038.

The Future of Nuclear and Hydropower

While the share of electric power provided for by nuclear energy has declined for quite some time, it is now starting to pick up again. While some European countries have announced that they will either completely discontinue or reduce reliance on nuclear power, other countries are looking forward to continued or even increased reliance on this source. Outside of Europe, no country currently using nuclear energy envisages complete discontinuation (not even Japan, notwithstanding the accident in Fukushima Daichi) and most of them envisage significant growth (China especially). The list of emerging countries considering acquiring a nuclear component to their power generation fleet is long, and some current nuclear technology proficient countries are keen suppliers (Russia, France, South Korea and more). Expectations about the potential role of a new generation of small and medium-sized nuclear reactors (SMRs) are high, and competition between numerous potential providers is very intense.

Hydropower is the largest source of renewable electricity globally, and is dispatchable to a certain extent. There is still some potential for increasing hydropower capacity in Europe, and huge untapped potential especially in Africa and Latin America.

Competition between gas and nuclear or hydropower is less intense than with coal in the short term, because the gestation of nuclear or hydro power plants is long, and SMRs are not commercially available yet; but in the long run it may have much greater impact, because coal is a carbon intensive solution, while nuclear and hydro are carbon-free.

Consequently, expectations about nuclear and hydro have direct bearing on expectations about the future of gas. Potentially, nuclear and hydropower can substitute for fossil gas completely, providing cheap electricity for base as well as variable and peak load, and also for producing zero-carbon hydrogen, or for direct capture of CO_2 from air and consequently for the production of synthetic hydrocarbons for those uses in which an energy-dense and liquid fuel is needed (e.g. aviation). A future with only nuclear and hydro, and no fossil gas is technically conceivable. Indeed, it is almost a reality in Norway (100% hydro), Sweden and Switzerland (relying on a combination of hydro and nuclear), but not credibly implementable in the span of the next thirty years (by 2050).

The Future of Non-Dispatchable Renewable Sources

In the past decade, competition between natural gas and non-dispatchable renewable sources (solar and wind) has been intense. Non-dispatchability is a major problem, because grid stability requires that demand and supply be balanced instantaneously at any moment in time, and the flexibility that is necessary to achieve this has overwhelmingly been provided for by the supply side. The predominant doctrine has been that electricity is an essential service and providers are expected to satisfy demand at all times, independently of its ups and downs. Because we do not control the availability of solar and wind energy (they are non-dispatchable), as the share of the latter increases it is only the remaining dispatchable sources that can be relied upon to guarantee grid stability. As long as non-dispatchable sources account for a small share of total power generation, the problem is relatively easy to solve. But when non-dispatchable sources account for a significant, or (in some scenarios) even dominant share of power generation, the difficulty of solving the problem grows exponentially.

Gas being a very flexible source of power generation, one line of thinking is that in the longer run growing penetration of non-dispatchable sources will lead to greater reliance on gas in power generation. This would mean that initially non-dispatchable renewables will displace gas, but past some level of penetration they will need to be paired with it.

However, flexibility can be obtained with solutions different from reliance on gas. Hydropower and nuclear are also capable of providing flexibility, albeit not as effectively as natural gas. In addition, there are batteries, hydrogen and, finally, demand flexibility. Greater reliance on batteries (and growing reliance on electricity in general) requires much higher demand for metals, and massive expansion of mining operations. In this sense, there is competition between natural gas and mining of metals. Hydrogen is an energy carrier which may be produced from gas (with CCS) but also competes with it and potentially displaces it. Demand flexibility also competes with gas, assuming that flexibility is acceptable to consumers (the assumption is that they would rely on batteries, not that they would adapt actual final demand to production).

The Future of Biomass

Biomass competes with fossil gas because it can be used as fuel in power generation; or be the source of biogas and biomethane. The limit to the substitution of methane with biomass is given by the limited availability of the latter, and potential competition with food crops on one hand and the extension of forested land on the other. Improved use of biomass will not only allow reducing emissions of methane in the atmosphere, but also to some extent displace fossil methane by providing a share of total methane supply, or offering an alternative to burning methane.

The Future of Electricity

Power generation is an important final use of methane, but it is not the most important one. Electricity today accounts for roughly 20% of total global final uses. The remaining 80% are thermal uses which rely overwhelmingly on burning fossil fuels or traditional biomass. The share of final uses relying on electricity has been growing constantly, and this will continue in the coming years. The question is: how fast will reliance on electricity increase?

The answer is relevant for our vision of the future of natural gas from two opposite points of view. Rapid increase in electricity demand is unlikely to be satisfied by a limited array of technologies: gas in power generation is more likely to continue to be in demand if the demand for electricity is very dynamic. At the same time, electricity can displace gas in several final uses, notably in industry and in buildings (heating, cooking).

At the retail level, gas and electricity support two parallel grids that reach a huge number of retail consumers. A gas network is not available everywhere, and many hundreds of millions people worldwide are not connected to the electricity grid, but having access to two parallel grids is a form of diversification that contributes to resilience. If you only have one grid, and that is lost for whatever reason, you have no fallback position. Furthermore, it is much easier to store gas and accommodate seasonal demand differences with that rather than with electricity. Hence, total elimination of the gas grid and exclusive reliance on electricity may not be advisable.

That said, a gas grid may be maintained, but used for hydrogen rather than methane. Hydrogen in turn can be produced either from methane or from electricity, so hydrogen production is a further layer of competition between gas and electricity.

The Future of Oil

Oil is the dominant fuel in the transport sector, but remains important in stationary uses, notably in buildings. Thus, a first level of competition between oil and gas is in the market for heating residential and commercial buildings. In some countries, notably in the Middle East, oil also remains important in power generation, and may eventually be displaced by gas depending on the relative availability of these hydrocarbons.

At the same time, natural gas can also compete with oil in the market for transportation fuels. It can do so in automotive or commercial vehicles in the form of compressed natural gas (CNG), or in the form of other fuels derived from methane, such as notably methanol or dimethyl ether (DME). In more complex gas-to-liquids plants methane can also be transformed into very pure diesel or aviation kerosene. The commercial viability of these processes essentially depends on the price difference between oil and methane: if oil is cheap, liquids from gas will not be competitive. Finally, in heavier uses (shipping, heavy truck or other commercial traffic) natural gas can be used in its liquefied form (LNG), especially in fleet use along regularly travelled routes, where the creation of sufficient refuelling facilities is possible.

In all the above uses, gas enjoys the advantage of somewhat lower carbon emissions than oil, therefore becoming more competitive the higher the price imposed on carbon is (and, obviously, the higher the difference between the price of oil and the price of gas).

The Future of Hydrogen

Hydrogen is a fuel carrier which is expected to play a fundamental role in decarbonising our economies, although views differ considerably on exactly how this might take place. Hydrogen can be produced in several ways, of which the two most frequently discussed ones are from water through electrolysis and from methane through steam reforming. The electricity needed for water electrolysis may be generated from renewable sources only, from nuclear energy or from fossil fuels (including methane). Therefore, hydrogen production may become a new source of methane demand (or, hydrogen production can be seen as a way to decarbonise methane).

Hydrogen can be viewed as a form of electricity storage (producing it when electricity is available in excess of demand, and generating from it when demand exceeds availability), hence reducing the need for flexibility provided by natural gas and undermining demand for it. Alternatively, it may be viewed as the solution for maintaining the value of existing gas networks and providing a future for the gas industry in a decarbonised world through massive conversion of methane into hydrogen with CCS. Any intermediate point can be chosen between these two extremes, especially if zero-carbon hydrogen from nuclear or hydropower is also allowed to enter the fray.

Which Role for Natural Gas?

It will be evident from the above that the view of the role of natural gas as a transitional source of energy critically depends on which assumptions one formulates about the rest of the array of primary sources of energy. If assumptions are that CCS will never become widespread; coal will decline but nuclear will grow much more rapidly than commonly expected; non-dispatchable renewables will grow rapidly with flexibility provided by batteries; and the role of electricity in final uses will also grow very rapidly, future demand for gas would essentially be restricted to final uses not covered by electricity, including possibly some substitution for oil products in transport.

The importance of natural gas as a transitional energy source varies significantly not only according to its competitors, but also considering the sector of consumption. Switching to natural gas, in fact, would not have the same impact on carbon emissions in every sector, or the same feasibility.

The transportation sector is an area where gas can play a role as a substitute to traditional fuels. However, while the potential for natural gas in transportation is high, natural gas vehicles (NGVs) technology is already well-developed, only a few countries in the world make an extensive use of natural gas propelled vehicles: China, Iran, India, and Pakistan accounted for more than 50% of the global share of NGVs. In the US, LNG accounted for just 4% of the total fuels used in transportation in 2020.[4]

Much as in the industrial sector, natural gas can present a bridge until the main challenges for electric vehicles are

[4] *A review of prospects for natural gas as a fuel in road transport*, The Oxford Institute for Energy Studies, University of Oxford, April 2019.

overcome, especially for heavy vehicles, where the size and cost-effectiveness of batteries are still a major limit to development.[5] Natural gas can also play a role in maritime transport, a sector where electric alternatives are not yet viable. Electric ships, even for short distances like ferry services, still face two major issues:[6] the battery capacity, and the necessity for a significant upgrade of port infrastructures and equipment to meet the needs of electrically powered vessels. Therefore, LNG could constitute a bridge between the highly polluting marine fuels used today and a future with ships powered by renewables. In early 2021, LNG-propelled ships accounted for 13% of new orders, with a growth forecast helped by their lower carbon footprint and the expansion of LNG infrastructures in port hubs worldwide.

If, on the other hand, a less extreme set of assumptions is retained (acceptance and success of CCS prompted by rising carbon prices; decline of coal in power generation and other uses, with much of it substituted by natural gas; growing role of nuclear and hydropower, but with limited dynamism especially in the next two decades, picking up more in the latter part of the century; slow-down of penetration of non-dispatchable renewables and batteries, notably also because of rising cost of metals and concern for the environmental impact of mining for them; successful transformation of the methane network into a hydrogen network with large volumes of hydrogen obtained from steam reforming of methane with CCS) fossil methane, with the complement of biomethane, may be expected to play a continuing important role well until the middle of the current century, and probably longer.

What might be the most plausible set of assumptions may be the subject of endless discussion and speculation. Just one point needs to be made before concluding this analysis: government policies and societal preferences are obviously important,

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[5] Ibid.

[6] S. Anwar, M.Y. Irfan Zia, M. Rashid, G. Zarazua de Rubens, and P. Enevoldsen, "Towards Ferry Electrification in the Maritime Sector", *Energies*, vol. 13, no. 24, 2020.

but market realities may be more important than frequently admitted. Fossil natural gas is an abundant and convenient source of energy which is very likely to remain strongly competitive. Individual countries or groups of countries may adopt policies that will erode this competitiveness and even simply legislate the abandonment of the use of gas, but this will only allow other countries to access gas at improved conditions. In the end, unless we assume a return to protectionism end economic isolationism, market realities cannot be forgotten.

It is probably too early to envisage the end of fossil natural gas.

6. The Future of Sustainable Mobility

6.1 Potential and Critical Issues of Electric Vehicles Development

Kenneth Gillingham, Stephanie Weber

Introduction

The transport sector has often been considered among the most difficult to decarbonise due to the lack of substitutes to petrol and diesel-powered vehicles. However, over the past decade, electric vehicle technology has dramatically improved. For example, average battery prices have fallen precipitously – 89% since 2010 – from above US$1100/kWh to US$137/kWh in 2020.[1] Commensurately, larger battery packs are being used in electric vehicles, with multiple current offerings on the market providing over 350 kilometres of range. And the offerings themselves are multiplying, with over 370 different electric car models available worldwide, covering nearly all vehicle classes.[2] Promising technological developments are also underway in heavy-duty electric vehicles.

[1] Bloomberg New Energy Finance, "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh", *BloombergNEF*, 16 December 2020.

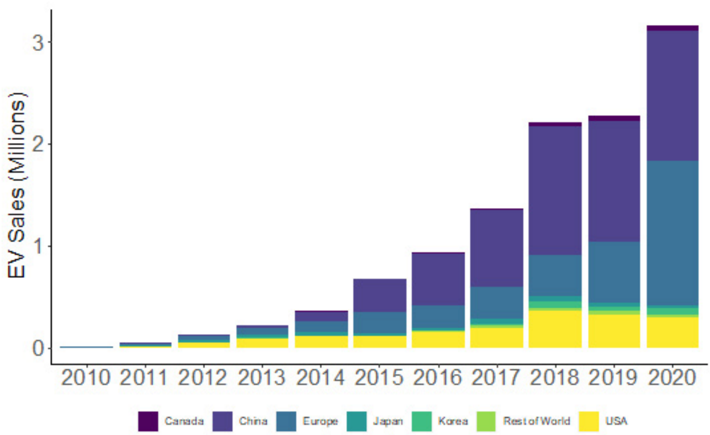
[2] International Energy Agency (IEA), *Global EV Outlook 2020*, 2020.

Electric vehicles are quickly growing in prominence and are likely to be a major force shaping paths of decarbonisation around the world in the upcoming decades, yet a smooth transition will require policymaker attention to critical issues, especially relating to enabling infrastructure. In this chapter, we review trends in electric vehicle sales, lay out the economic motivation for electric vehicle policy, and discuss current policies in effect as well as the evidence on the environmental effects of electric vehicles.

Trends in electric vehicle sales

In 2010, only 12,000 electric vehicles were sold worldwide. By 2020, this number had reached three million.[3] As shown in Figure 1, nearly half of these sales have been in China. Roughly 30% are in Europe and 15% in the United States.

Fig. 1 - Global electric vehicle sales (all vehicle classes and powertrains) by year and country

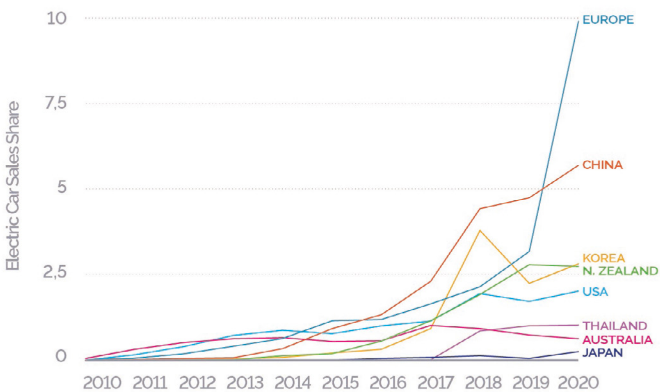


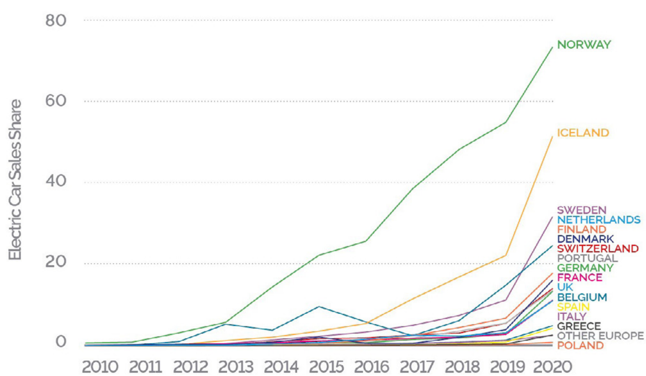
Data source: IEA Global EV Data Explorer

[3] Here sales are defined as all battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles, although fuel cell vehicles are a minimal contribution to the total.

As overall electric vehicle sales have increased, their share of sales has increased as well. Figure 2 shows the sales share of electric vehicles by country. The top panel aggregates Europe into a single line, while the bottom disaggregates Europe. Norway has an impressive sales share of nearly 75% in 2020, which far exceeds other major markets, such as China (5.7%) and the United States (2%).

FIG. 2 - SHARE OF NEW CAR SALES THAT ARE ELECTRIC IN EACH REGION/COUNTRY





Data source: IEA Global EV Data Explorer

Over 90% of electric vehicles on the road today are light-duty passenger vehicles. Electricity is also beginning to be used to power medium- and heavy-duty commercial vehicles (vans and trucks) and buses, with some 600,000 electric buses and 500,000 electric vans on the roads worldwide today. More than 97% of these electric buses are in China, but electric buses are also being used in Chile, Colombia, and India. 94% of electric trucks are in China, with most of the remainder in Europe. Electric vans are more widely distributed, with 60% in China, 30% in Europe, 3% in Korea and 2% in Japan.

Projections for the future

There are a wide range of projections about future sales of electric vehicles going forward, but many are very optimistic. Bloomberg New Energy Finance (BNEF) projects that batteries will fall below US$100/kWh in 2023, the point at which price parity for mid-range electric vehicles is likely[4] and may reach US$58/kWh by 2030.[5] This corresponds to a 30% global market share for new vehicles by 2030 and 60% by 2050. The International Energy Agency (IEA) projects that based on stated policies, electric vehicles will make up 17% of passenger vehicle sales by 2030, and under stronger assumptions, the market share could be 35%.[6] Of course, there is considerable uncertainty around any of these projections as they rely on assumptions about future technology and policy. But it is notable that 18 of the 20 largest automakers have announced plans to introduce additional electric vehicle models, and some, like General Motors, state that they plan to end production of non-electric vehicles entirely by 2035.

Several industry experts are also optimistic about the prospects for continued electrification of buses, delivery vans,

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[4] While price parity may be achieved at different times around the world, BNEF projects that price parity for all light-duty vehicle segments will occur in Europe in 2025-2027 (2021).

[5] Bloomberg New Energy Finance, *Electric Vehicle Outlook*, BloombergNEF, 2020.

[6] IEA (2020).

and two- or three-wheeled vehicles. However, there remain major challenges for medium- and heavy-duty trucks. Heavy-duty vehicles, which can carry loads in excess of 13 tons, are often used in long-haul shipping, and may travel hundreds of miles per day. Accordingly, they need large batteries, which poses an issue for weight restrictions and, in the absence of very fast charging, may lead to very long charging times. Thus, the adoption of electric trucks may depend on the buildout of a high-speed charging network where sleeper trucks can spend the night in addition to continued improvement in technology. Such a charging network will pose a very substantial burden on the electricity grid and would require serious investments. In contrast, short-haul trucks used in cities may be able to transition to electric vehicles more rapidly, as they are lighter, drive shorter distances, and are able to charge between uses like conventional vehicles.[7] Regardless, electric vehicle trucks are beginning to be introduced in large numbers by truck manufacturers in both categories.[8]

Economic motivation for electric vehicle policy

Why is there so much attention given to electric vehicles by policymakers? From an economics perspective, there are a set of market failures and behavioural biases that motivate electric vehicle policy. These are summarised in Table 1 where possible policy actions for each are listed. The policy options listed for each issue may not perfectly address the issue, but they each have potential – if well-designed – to improve social welfare. We discuss each issue below before moving to policy actions in the next section.

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[7] Major companies, including Amazon, DHL and FedEx, have made commitments to purchase commercial electric vehicles for their operations.

[8] J. Hitch, "U.S. heavy-duty ZEV models to grow 250% by 2023", FleetOwner, 21 May 2021.

TAB. 1 - THE MARKET FAILURES AND BEHAVIOURAL BIASES AT PLAY IN THE ELECTRIC VEHICLE MARKET (THE COLUMN ON THE RIGHT DESCRIBES THE POLICIES THAT CAN ADDRESS EACH ISSUE)

Market failure or behavioural bias	Possible Policy Actions
Environmental externalities	Directly pricing pollution EV subsidies (or ICE taxes, fuel economy standards, sales targets)
Innovation market failures	EV subsidies Research/manufacturing subsidies
Indirect network effects	EV subsidies Public charging investments Standardisation of charging equipment
Split incentives	Public charging investments Building standards
Information market failures	Informational campaigns Subsidies to drive peer effects
Undervaluation of future fuel savings	Information Subsidies

Environmental externalities - Petrol and diesel internal combustion engines produce greenhouse gases and local air pollutants that affect the climate and human health. Existing policies, such as fuel taxes or low carbon fuel standards, may partly (or in rare cases entirely) internalise these externalities. Coady et al. calculate that in nearly all countries, current policies are far from addressing these externalities from conventional vehicles, and this is exacerbated by fossil fuel subsidies in many countries.[9]
Innovation market failures - New technologies may exhibit large spillovers from the innovation process that firms do not consider when deciding how much to invest in the technologies. Some benefits of research and development may spill over to other firms by pushing the technology forward. Similarly, costs often fall with cumulative experience in producing a new technology (i.e., learning-by-doing), and the cost decline

[9] D. Coady, I. Parry, L. Sears, and B. Shang, "How Large Are Global Energy Subsidies?", *IMF Working Papers 15*, 2015.

spills over to other firms.[10] The cost declines in electric vehicle technology over the past decade suggest innovation market failures, although they have yet to be demonstrated in the empirical literature.

Indirect network effects - The appeal of electric vehicle adoption increases with the size of the charging network, and the benefits of building a new charging station are likewise affected by the number of electric vehicles. This can lead to a chicken-and-egg problem where both sides of the market remain inefficiently small.[11] This issue may be even more complex when different charging technologies exist.[12] It could also apply to the electricity infrastructure investment needed to handle a full transition to electric vehicles.

Split incentive problems - Because electric vehicle owners often charge at home, many electric vehicle owners purchase charging equipment to speed up at-home charging. Renters may not want to make upgrades to a residence they do not own, and landlords have little incentive to do so. This effect has been shown to occur in energy efficiency,[13] and the evidence of a homeowner-renter gap in electric vehicle ownership suggests a similar issue in electric vehicles.[14]

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[10] A. van Benthem, K. Gillingham, and J. Sweeney, "Learning-by-Doing and the Optimal Solar Policy in California Author", *Energy Journal*, vol. 29, 2014, pp. 131-151; K. Gillingham and J.H. Stock, "The cost of reducing greenhouse gas emissions", *Journal of Economic Perspectives*, vol. 32, 2018, pp. 53-72.

[11] S. Li, L. Tong, J. Xing, and Y. Zhou, "The Market for Electric Vehicles : Indirect Network Effects and Policy Design", *Journal of the Association of Environmental and Resource Economists*, vol. 4, 2017, pp. 89-133; K, Springel, "Network Externality and Subsidy Structure in Two-Sided Markets : Evidence from Electric Vehicle Incentives", *American Economic Journal*, American Economic Association, 2020, pp. 1-63.

[12] J. Li, *Compatibility and Investment in the U.S. Electric Vehicle Market*, Mit.Edu, 2019.

[13] L.W. Davis, Evaluating the Slow Adoption of Energy Efficient Investments. The Design and Implementation of US Climate Policy, National Bureau of Economic Research, June 2010, pp. 301-316; K. Gillingham, M. Harding, and D. Rapson, "Split incentives in residential energy consumption", *Energy Journal*, vol. 33, 2012, pp. 37-62.

[14] L.W. Davis, "Evidence of a homeowner-renter gap for electric vehicles",

Information market failures - Standard economic models assume buyers are fully informed about the expected utility they would receive from purchasing a given vehicle, but prospective vehicle buyers often lack information about new electric vehicle technologies.[15] This may include the driving patterns that people will actually use and their access to charging stations, perhaps incorrectly contributing to "range anxiety" which might lead consumers to view electric vehicles more cautiously than if they were fully informed. Lack of information or biased beliefs may correct over time as electric vehicles become more standard, but such a correction might be expedited by policy.
Undervaluation of future fuel savings - Consumers may undervalue the future fuel savings from purchasing a more-efficient vehicle or electric vehicle relative to other decisions in their lives. The costs of owning and operating an electric vehicle are much lower than the costs of conventional vehicles, so it is likely that some consumers would save money by purchasing an electric vehicle, even though the upfront costs are higher. While there is no published evidence of undervaluation for electric vehicles, there is mixed evidence on undervaluation for conventional vehicles, with some studies suggesting that consumers undervalue fuel economy.[16] An explanation for

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Applied Economics Letters, vol. 26, no. 11, 2019, pp. 927-932.

[15] R.M. Krause, S.R. Carley, B.W. Lane, and J.D. Graham, "Perception and reality: Public knowledge of plug-in electric vehicles in 21 U.S. cities", *Energy Policy*, vol. 63, 2013, pp. 433-440.

[16] M.R. Busse, C.R. Knittel, and F. Zettelmeyer, "Are consumers myopic? Evidence from new and used car purchases", *American Economic Review*, vol. 103, 2013, pp. 220-256; H. Allcott and N. Wozny, "Gasoline Prices, Fuel Economy, and the Energy Paradox", *Review of Economics and Statistics*, vol. 96, 2014, pp. 638-647. "Our identification out-performs standard long-run restrictions by significantly reducing the bias in the short-run impulse responses and raising their estimation precision. Unlike its long-run restriction counterpart, when our Max Share identification technique is applied to U.S. data, it delivers the robust result that hours worked responds negatively to positive technology shocks. We investigate whether car buyers are myopic about future fuel costs. We estimate the effect of gasoline prices on short-run equilibrium prices of cars of different fuel economies. We then compare the implied changes in willingness-to-pay to

this could be that consumers are acting myopically in their car purchasing behaviour, but other explanations are possible too.

Electric Vehicle Policy in Practice

Policies to induce demand

Subsidies (either direct to consumers or indirect through automakers) are perhaps the most straightforward and common policy to promote electric vehicles used around the world. They have been implemented at the national and/or subnational level in locations such as China, Europe, the United States, as well as Japan, South Korea, India, the Philippines, Malaysia, Australia, New Zealand, Morocco, South Africa, Russia, Kyrgyzstan, Costa Rica and Brazil. In many countries, the subsidies have been large. For example, the United States provides a US$7500 tax incentive on top of additional incentives of several thousand dollars from many states.

Considerable evidence, mostly from the United States and Canada, demonstrates that subsidies[17] for electric vehicles (and hybrids) have had a meaningful impact, increasing sales from 2.5-20% per US$1000 of incentive.[18] Policy efficacy depends

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the associated changes in expected future gasoline costs for cars of different fuel economies in order to calculate implicit discount rates. Using different assumptions about annual mileage, survival rates, and demand elasticities, we calculate a range of implicit discount rates similar to the range of interest rates paid by car buyers who borrow. We interpret this as showing little evidence of consumer myopia". K. Gillingham, S. Houde, and A. van Benthem, *Consumer Myopia in Vehicle Purchases: Evidence from a Natural Experiment*, National Bureau of Economic Research, May 2019.

[17] Note that we refer to all policies that reduce up-front purchase price as a 'subsidy,' but there is evidence that the form of the incentive may affect outcomes. In the US, the subsidies are offered as tax rebates, and Clinton and Steinberg (2019) find that such rebates may be less effective than more direct cost reductions.

[18] A. Jenn, K. Springel, and A.R. Gopal, "Effectiveness of electric vehicle

in part on timing. Both Li et al. (2017) and Springel (2020) found spending on charging stations is more effective at increasing electric vehicle purchases than spending on subsidies in the early stages of the market, but this changes as the market matures.[19] There have been some concerns about the extent to which these subsidies go to inframarginal purchasers who would have purchased an electric vehicle anyway and to the wealthy.[20] [21]

Related policies reduce the cost of electric vehicle ownership or make electric vehicles more valuable to drive. For instance, several European countries waive annual registration costs for electric vehicle owners, while Mexico does not require electric vehicles to participate in regular vehicle inspections. In other places, electric vehicles are given preferential access to bus or high-occupancy vehicle (HOV) lanes and free or reduced tolls or parking. However, the evidence on whether HOV or bus lane access increases adoption is mixed.[22]

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incentives in the United States", *Energy Policy*, vol. 119, 2018, pp. 349-356; B.C. Clinton and D.C. Steinberg, "Providing the Spark : Impact of financial incentives on battery electric vehicle adoption", *Journal of Environmental Economics and Management*, vol. 98, 2019, pp. 102-255; E. Muehlegger and D.S. Rapson, Subsidizing Low- and Middle-Income Adoption of Electric Vehicles: Quasi-Experimental Evidence from California, 2020.

[19] S. Li, L. Tong, J. Xing, and Y. Zhou (2017); and K. Springel (2020).

[20] There is similar debate about the extent of free-riding for hybrid petrol vehicles (A. Chandra, S. Gulati, and M. Kandlikar, "Green Drivers or Free Riders? An Analysis of Tax Rebates for Hybrid Vehicles", *Journal of Environmental Economics and Management*, vol. 60, 2010, pp. 78-93; A. Beresteanu and S. Li, "Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles in the United States", *International Economic Review*, vol. 52, 2011, pp. 161-182; K.S. Gallagher and E. Muehlegger, "Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology", *Journal of Environmental Economics and Management*, vol. 61, 2011, pp. 1-15.

[21] S. Borenstein and L.W. Davis, "The distributional effects of US clean energy tax credits", *Tax Policy and the Economy*, vol. 30, 2016, pp. 191-234.

[22] K.S. Gallagher and E. Muehlegger (2011); K.Y. Bjerkan, T.E. Nørbech, and M.E. Nordtømme, "Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway. Transportation Research Part D", *Transport and Environment*, vol. 43, 2016, pp. 169-180; A.C. Mersky, F. Sprei, C. Samaras, and

The largest component of ownership costs is the expense of charging. The split incentive problem discussed above can be at least partly addressed by incentivising home charging systems and making public charging more accessible. For example, in California, one of the major utilities, PG&E, is building new charging stations in or near multifamily residences. Additionally, building standards for multi-unit housing can require that a certain amount of vehicle charging is available, as is the case in the European Union. Policies can also encourage charging at optimal times. Many utilities around the world have implemented time-of-use rates for electric vehicles, and evidence suggests that households can adjust the timing of their charging to take advantage of lower electricity prices in the off-peak.[23] Such programmes have the potential to both reduce the cost of electric vehicle ownership and, if electricity prices are set to match the social cost of provision, reduce the overall costs of electricity generation.[24]

Many governments have also directly invested in charging infrastructure, subsidising or directly building charging stations. In Norway and the United States, these policies have been shown to be effective at promoting electric vehicle adoption: in the early part of the 2010s, a dollar of spending on charging stations was twice as effective as a dollar of spending

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Z.S. Qian, "Effectiveness of incentives on electric vehicle adoption in Norway. Transportation Research Part D", *Transport and Environment*, vol. 46, 2016, pp. 56-68; A. Jenn, K. Springel, and A.R. Gopal (2018); A. Jenn, J.H. Lee, S. Hardman, and G. Tal; "An in-depth examination of electric vehicle incentives: Consumer heterogeneity and changing response over time. Transportation Research Part A", *Policy and Practice*, vol. 132, 2020, pp. 97-109.

[23] J. Burkhardt, K. Gillingham, and P.K. Kopalle, *Experimental Evidence on the Effect of Information and Pricing on Residential Electricity Consumption*, National Bureau of Economic Research, February 2019.

[24] Borenstein and Bushnell show that electricity prices deviate from social marginal cost across the United States, although in some regions it is too high and in others too low (S. Borenstein and J.B. Bushnell, *Do Two Electricity Pricing Wrongs Make a Right? Cost Recovery, Externalities, and Efficiency*, National Bureau of Economic Research (NBER), 2018).

on purchase subsidies.[25] However, as spending on charging stations increases and stations are built out, the marginal value of charging subsidies decreases, and it does so faster than the marginal value of purchase subsidies.

Many of the same policies have been employed for other classes of vehicles. Purchases of electric buses and medium-duty commercial vehicles have been subsidised in China, India, the European Union, the US, Canada, New Zealand, Chile and Colombia. In parts of the Netherlands, medium- and heavy-duty alternative fuel vehicles get preferential access to commercial areas in cities. In California, commercial electric vehicles can slightly exceed weight class limits. Investment in heavy-duty vehicle charging infrastructure is also widespread, with strategic corridors in the United Kingdom and bus and truck charging stations being built by utilities in California.

Policies to induce supply of electric vehicles

Many policies encourage electric vehicles by targeting manufacturer decisions. Some of this is investment to spur innovation: China, Japan, the European Union, Canada, India and the United States have funded different stages of battery research and development (R&D) in the hope of reducing costs and supporting domestic industries. While the effects of battery-specific R&D are understudied, evidence from electricity technologies suggests that correcting R&D market failures is somewhat less important than correcting the environmental market failures in the short run.[26]

There are also policies to incentivise electric vehicle production by automakers, including incorporating incentives into fuel economy or tailpipe emission standards, Zero Emission Vehicle (ZEV) mandates and bans of internal combustion

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[25] S. Li, L. Tong, J. Xing, and Y. Zhou (2017); K. Springel (2020).

[26] C. Fischer, L. Preonas, and R.G. Newell, "Environmental and Technology Policy Options in the Electricity Sector: Are We Deploying Too Many ?", *Journal of the Association of Environmental and Resource Economists*, vol. 4, 2017.

engine vehicle sales. Fuel economy standards set a minimum average fuel economy for each automaker (often with the standard set for each vehicle fleet or for each vehicle footprint or weight class) and have been implemented around the world, including in the United States, Europe, China and Japan. Under US regulations, electric vehicles are treated generously: they are assumed to produce zero grams of carbon dioxide per mile under tailpipe standards (ignoring any upstream emissions from electricity generation) and have been included in the average emissions calculations with a "credit multiplier" that counts each electric vehicle more than once (a similar credit has been used for heavy-duty truck standards). This approach can reduce the overall stringency of the standards, increase vehicle emissions,[27] and may even undermine the demand for electric vehicles.[28]

ZEV mandates require that ZEVs make up a certain percent of vehicles sold by a manufacturer. They have been used in several US states. The effect of ZEV mandates on emissions depends on the emissions of the vehicles incentivised by the policy, including the upstream emissions and the mileage by fuel source among plug-in hybrids.[29]

Several countries and sub-national jurisdictions have announced deadlines for phasing out internal combustion engine vehicles, which is essentially a 100% ZEV mandate. This approach can allow deeper decarbonisation and might send a signal to the market to assure the appropriate infrastructure is developed. However, there is a concern about a type of "green

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[27] A. Jenn, I.M.L. Azevedo, and J.J. Michalek, "Alternative Fuel Vehicle Adoption Increases Fleet Gasoline Consumption and Greenhouse Gas Emissions under United States Corporate Average Fuel Economy Policy and Greenhouse Gas Emissions Standards", *Environmental Science and Technology*, vol. 50, 2016, pp. 2165-2174.

[28] K.T. Gillingham, *Designing Fuel Economy Standards in Light of Electric Vehicles*, National Bureau of Economic Research (NBER), 2021.

[29] A. Jenn, I.M.L. Azevedo, and J.J. Michalek, "Alternative-fuel-vehicle policy interactions increase U.S. greenhouse gas emissions", *Transportation Research Part A: Policy and Practice*, 2019, vol. 124, pp. 396-407.

paradox", whereby such deadlines could lead to a spike in conventional vehicle purchases before the deadline. A more gradual phaseout with bankable quotas for internal combustion engine vehicles might be more likely to improve social welfare because of its flexibility.[30]

Environmental Effects

Whether pro-electric vehicle policies reduce emissions depends on the direct pollution produced by an additional electric vehicle and the avoided pollution that would have been produced had the electric vehicle not been available and a conventional vehicle used instead.

Emissions from electric vehicles

Emissions from electric vehicle usage depend on the emissions generated by the power source used to charge the vehicle. This generation on the margin varies widely with where the electric vehicle is and what time the charging occurs. For example, in the United States, marginal carbon dioxide emissions in the upper Midwest exceed those in California by a factor of three, driven by differences in generation by coal or natural gas.[31]

Differences in marginal generation over the course of the day are similarly variable. Locations with a lot of baseload coal plants and charging overnight (when electricity is cheapest and most people are at home) produce much higher emissions than if charging occurs in the middle of the day, when electricity is

[30] S.P. Holland, E.T. Mansur, and A.J. Yates, *The Electric Vehicle Transition and the Economics of Banning Gasoline Vehicles*, National Bureau of Economic Research (NBER), February 2020.

[31] J.S. Graff Zivin, M.J. Kotchen, and E.T. Mansur, "Spatial and temporal heterogeneity of marginal emissions: Implications for electric cars and other electricity-shifting policies", *Journal of Economic Behavior and Organization*, vol. 107, 2014, pp. 248-268; S.P. Holland, E.T. Mansur, N.Z. Muller, and A.J. Yates, *Distributional Effects of Air Pollution from Electric Vehicle Adoption*, National Bureau of Economic Research (NBER), November 2016.

more expensive but natural gas is more likely to be marginal. This is already becoming less important in the United States and other places in the world where coal plant capacity is declining,[32] which improves the environmental benefits of electric vehicles charged overnight.

Over a longer time horizon, higher levels of electric vehicle demand could alter power plant construction and retirement decisions, possibly even increasing emissions if coal plants are run more or retired later due to the additional electricity demand, but this is only likely to happen in cases with high shares of coal generation that remains financially viable.[33]

Emissions from electric vehicles also depend on how much electricity a given vehicle requires per mile. Notably, this can vary by region due to the impact of temperature on battery performance – electric vehicle battery efficiencies decline in extreme heat and extreme cold, requiring additional generation per mile driven.[34]

Avoided pollution

The pollution avoided by a switch to electric vehicles depends on what cars are replaced by the electric vehicles, how those cars would be driven, and where those cars would have been driven. There is a wide range of fuel efficiencies in vehicles currently on the road, and the emissions benefits of a new electric vehicle look vastly different if the car replaced is a conventional Ford F-150[35] or a Toyota Prius. Evidence from both California and

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[32] S.P. Holland, E.T. Mansur, N.Z. Muller, and A.J. Yates, "Decompositions and Policy Consequences of an Extraordinary Decline in Air Pollution from Electricity Generation", *American Economic Journal*, vol. 12, 2020, pp. 244-274.

[33] K. Gillingham, M. Ovaere, and S.M. Weber, *Carbon Policy and the Emissions Implications of Electric Vehicles*, National Bureau of Economic Research (NBER), March 2021.

[34] J. Archsmith, A. Kendall, and D. Rapson, "From Cradle to Junkyard: Assessing the Life Cycle Greenhouse Gas Benefits of Electric Vehicles", *Research in Transportation Economics*, vol. 52, 2015, pp. 72-90.

[35] Note that Ford has recently introduced an electric F-150: N.E. Boudette, "Ford's Electric F-150 Pickup Aims to Be the Model T of E.V.s", The New

US data suggests that people incentivised to buy an electric vehicle through a state subsidy programme would likely have purchased a fairly fuel-efficient car had they not purchased the electric vehicle.[36] A related issue is variation in miles driven. Here, too, there is reason to believe that – at least when it comes to the early adopters – electric vehicles are purchased by people who drive fewer miles, reducing the benefits associated with electric vehicles.[37] On the other hand, the avoided damage from the pollution will be higher in urban areas, and it is likely that electric vehicles will have a higher market share in urban areas than rural areas.

Combined effects

The environmental benefits of electric vehicles are thus based on the net of the additional emissions from electric vehicle charging and the avoided emissions from the switch to electric vehicles. Many areas of the world that are wealthier and more urban are better suited for early adoption of electric vehicles and have greater avoided emissions. In the United States, recent estimates suggest that in two thirds of urban counties, electric buses would reduce net pollution damage relative to diesel buses.[38]

The full cradle-to-grave emissions associated with vehicle production are also useful to note. Electric vehicle manufacturing, particularly the production of batteries, is estimated to be more environmentally harmful than the

York Times, 19 May 2021.

[36] J. Xing, B. Leard, and S. Li, "What Does an Electric Vehicle Replace?", *Journal of Environmental Economics and Management*, vol. 107, May 2021; E. Muehlegger and D.S. Rapson, *Correcting Estimates of Electric Vehicle Emissions Abatement : Implications for Climate Policy*, National Bureau of Economic Research (NBER), 2020, pp. 1-26.

[37] L.W. Davis, "How much are electric vehicles driven?", *Applied Economics Letters*, vol. 26, no. 18, 2019, pp. 1497-1502; F. Burlig, J.B. Bushnell, D.S. Rapson, and C. Wolfram, *Low Energy: Estimating Electric Vehicle Electricity Use*, National Bureau of Economic Research (NBER), February 2021.

[38] S.P. Holland, E.T. Mansur, N.Z. Muller, and A.J. Yates (2020).

manufacturing of conventional vehicles. However, the emissions of battery production are small relative to the lifecycle emissions from powering conventional or electric vehicles.[39]

The road ahead

Electric vehicles present a promising path to deeper decarbonisation, with improved technology and increased sales in recent years. Infrastructure and policy are crucial to a smooth transition. A wider range of drivers must adopt the new technology, a more complete charging infrastructure must be developed, there must be clean electricity charging the electric vehicles, and consumers must be incentivised to charge in a cost-effective and clean way. Many forecasts are quite optimistic about electric vehicles, but there remain potential obstacles, such as mainstream consumer acceptance and the need to build out a new refuelling infrastructure for fast charging, as well as the transmission and generation capacity to support it.

One obstacle not yet discussed is the challenge of managing the supply chain for critical metals used in producing batteries and other electric vehicle components. Potential shortages, and thus high prices, of lithium,[40] nickel[41] and cobalt[42] are worrying automakers and policymakers. Economising on the use of more expensive metals,[43] developing replacements for the current

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[39] D.A. Notter, M. Gauch, R. Widmer, P. Wäger, A. Stamp, R. Zah, and H.J. Althaus, "Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles", *Environmental Science & Technology*, vol. 44, no. 17, 2010, pp. 6550-6556; J. Archsmith, A. Kendall, and D. Rapson (2015).

[40] G. Burdick, "Battery makers face looming shortages of high-quality lithium", UtilityDive, 25 June 2020.

[41] "Tesla partners with nickel mine amid shortage fears", BBC News, 5 March 2021.

[42] L. Mucha, T.C. Frankel, and K. Domb Sadof, "The hidden costs of cobalt mining", The Washington Post, 28 February 2018. Cobalt in particular faces concerns about the environmental and social impact of mining, which almost entirely occurs in the Democratic Republic of Congo (though there are local environmental costs to mining lithium and nickel, as well).

[43] M. Muratori et al., "The rise of electric vehicles - 2020 status and future

battery technology and improving battery recycling approaches and availability are all potentially important paths forward.[44]

One other challenge worth noting is that many governments are reliant on fuel tax revenue from petrol and diesel to fund road maintenance and other infrastructure investments. Electric vehicle adoption has reduced government revenues in the United States by US$250 million per year[45] and this could increase to as much as US$900 million by 2025.[46] This may lead to political pressure to increase annual registration fees on electric vehicles or impose fees per mile/kilometre driven. These fees targeted at electric vehicles could reduce the growth in electric vehicle ownership.

Current trends and industry projections strongly suggest that decarbonisation of transport will involve substantial electrification of vehicles. Such a transition will inherently involve policymaker attention on enabling infrastructure to ensure that this is a smooth transition.

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expectations", Progress in Energy, vol. 3, 2021.

[44] J. Xiao, J. Li, and Z. Xu, "Challenges to Future Development of Spent Lithium Ion Batteries Recovery from Environmental and Technological Perspectives", *Environmental Science and Technology*, vol. 54, no. 1, 2020; D. Mulvaney, R.M. Richards, M.D. Bazilian, E. Hensley, G. Clough, and S. Sridhar, "Progress towards a circular economy in materials to decarbonize electricity and mobility", *Renewable and Sustainable Energy Reviews*, vol. 137, March 2021.

[45] L.W. Davis and J.M. Sallee, "*Should Electric Vehicles Drivers Pay a Mileage Tax?*", The University of Chicago Press Journal, 2019; K. Gillingham, M. Ovaere, and S.M. Weber, *Carbon Policy and the Emissions Implications of Electric Vehicles*, National Bureau of Economic Research (NBER), March 2021.

[46] A. Jenn, I.L. Azevedo, and P. Fischbeck, "How will we fund our roads? A case of decreasing revenue from electric vehicles", *Transportation Research Part A, Policy and Practice*, vol. 74, April 2015, pp. 136-147.

6.2 The Role of Clean Hydrogen for a Sustainable Mobility

Nicola De Blasio

Hydrogen and energy have a long-shared history. Although there have been false starts in the past, this time around, hydrogen is capturing unprecedented political and business momentum as a versatile and sustainable energy carrier that could be the missing piece in the carbon-free energy puzzle. Clean hydrogen produced from zero-carbon energy sources, such as renewable (green hydrogen) and nuclear power (pink hydrogen),[1] appears ever more likely to play a prominent role in the global transition to a low-carbon economy.[2]

As governments and corporations become increasingly committed to addressing climate change and reducing emissions, they are placing greater emphasis on the deep decarbonisation of energy-intensive "hard-to-abate" sectors, such as iron and steel production, high-temperature industrial heat, aviation, shipping, railway, and long-distance road transportation. These are areas where shifting to electricity as the preferred energy vector while decarbonising its production may not be immediately feasible. At the same time, adoption of clean hydrogen at scale will depend on more than just its environmental benefits; economic, policy, technological, and safety factors must also be addressed.

This chapter analyses clean hydrogen's potential for driving emissions reductions in the mobility sector, focusing on road transportation, shipping, rail, and aviation. Overall,

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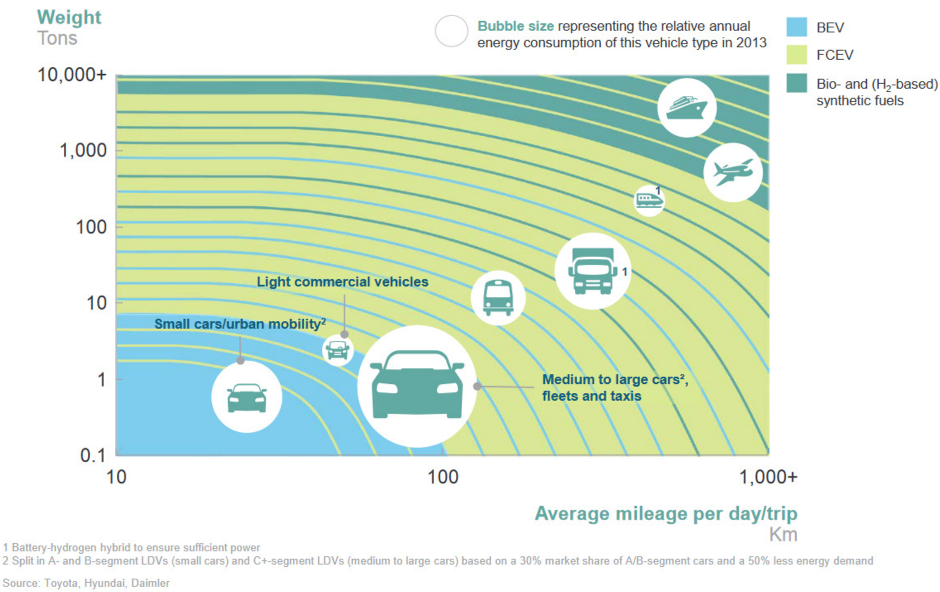
[1] Green hydrogen: produced through electrolysis using renewable electricity. Pink hydrogen: produced like green hydrogen but solely using electricity from nuclear power.

[2] F. Pflugmann and N. De Blasio, "The Geopolitics of Renewable Hydrogen in Low-Carbon Energy Markets", *Geopolitics, History, and International Relations*, vol. 12, no. 1, 2020, pp. 9-44. doi:10.22381/GHIR12120201.

transportation is the second-largest producer of global CO_2 emissions, after electricity and heat generation,[3] and one of the hardest sectors to decarbonise due to its distributed nature and the advantages provided by fossil fuels in terms of high energy densities, ease of transportation and storage. Figure 1 summarises for which mobility segments BEVs (battery electric vehicles), FCEVs (Fuel cell electric vehicles), and vehicles running on bio- and/or synthetic fuels are most applicable.

FIG. 1 - HYDROGEN APPLICATIONS IN THE MOBILITY SECTOR



Source: Hydrogen Council (2017)

[3] International Energy Agency (IEA), "Data & Statistics", 2021.

The Hydrogen Molecule - Production and Applications

Hydrogen is the most abundant element in the solar system, but on Earth it only occurs in compound form. Thus, hydrogen must be produced from molecules containing it through specific processes such as thermo-chemical conversion, biochemical conversion, or water electrolysis.

Annual global hydrogen production today stands at about 75 million tons (Mt) or 10 exajoules (EJ)[4] and stems almost entirely from natural gas (steam gas reforming) and coal (coal gasification).[5] Although hydrogen burns cleanly as a fuel at its point of use, producing it from fossil fuels without carbon capture simply relocates emissions. Hence, to reap hydrogen's full environmental benefits, it must be produced from zero-carbon electricity through water electrolysis, an electrochemical process that splits water into hydrogen and oxygen. Currently, however, water electrolysis accounts for less than 0.1% of global hydrogen production.[6]

Overall, two factors will determine hydrogen's rate of global growth: competitiveness of production costs and deployment of enabling infrastructure at scale. Today, green hydrogen is two to three times more expensive than hydrogen produced from fossil fuels.[7] However, thanks to innovation, economies of scale, and carbon pricing policies, these costs are expected to decrease.

Hydrogen is mainly used in oil refining and the production of ammonia, fertilisers, methanol and steel. Yet, with growing emphasis on its decarbonisation potential across sectors, hydrogen demand is projected to increase considerably in the coming decades. Estimates on annual global demand by

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[4] International Energy Agency (IEA), Energy Technology Perspectives 2020, September 2020.

[5] International Energy Agency (IEA), The Future of Hydrogen, June 2019.

[6] Ibid.

[7] IRENA (International Renewable Energy Agency), "Making Green Hydrogen a Cost-Competitive Climate Solution", 17 December 2020.

2050 vary significantly among scenarios. The 2017 Hydrogen Council study estimates demand at approximately 78 EJ, or around 14% of projected total global energy demand. Studies by BloombergNEF (2019), DNV (2018), and IEA (2020) are more conservative, with estimates between 5 and 40 EJ.

Clean hydrogen can be used in both stationary and mobility applications. As a readily dispatchable means of storing energy, hydrogen can help address growing intermittency and curtailment challenges associated with expanded renewable energy capacity. It can serve as a fuel in stationary systems for buildings, backup power, distributed generation or for high-temperature industrial heat. In mobility applications, hydrogen could become a key energy carrier for sustainable transportation. Whether by powering fuel-cell electric vehicles such as hydrogen cars, trucks, and trains, or as a feedstock for synthetic fuels for ships and planes, hydrogen can complement ongoing efforts to electrify road and rail transportation and provide a scalable option to decarbonise the shipping and aviation segments.

Hydrogen-powered vehicles offer key advantages including shorter refuelling times, longer ranges, and a lower material footprint compared to lithium battery-powered electric vehicles. However, high total costs of ownership and lack of enabling infrastructure are key challenges. Realising the promise of hydrogen as a sustainable mobility energy carrier will therefore require robust policy support, technological innovation, and committed investment.

Technology Focus - Hydrogen Fuel Cells and Electrolysis

Fuel cells convert hydrogen-rich fuels into electricity through a chemical reaction, with water and heat as the only by-products. A fuel cell consists of an anode, a cathode, and an electrolyte membrane. The stored hydrogen passes through the anode, where it is split into electrons and protons. Electrons pass through an external circuit, generating electric power which can be fed directly to a vehicle's electric motor or stored in batteries. Protons pass through the membrane to reach the cathode, where they combine with electrons and oxygen to produce water molecules.

Fuel cells offer a unique and wide range of potential applications: they can power systems as small as a laptop computer or as large as a utility power station and can replace internal combustion engines (ICE) in mobility applications. FCEVs use a fuel cell, rather than a battery, to power electric motors. FCEVs are a zero-emissions alternative to not only conventional ICE vehicles but also BEVs, which use lithium-ion batteries to store electrical energy produced outside the vehicle. Hydrogen FCEVs operate near-silently, since they have no moving parts and produce no tailpipe emissions. However, while clean burning by itself, hydrogen must be produced from renewable or nuclear energy to harness the full environmental benefits.

Electrolysis refers to the production of hydrogen and oxygen using electricity to split water and can be thought as the reverse process of a fuel cell. The reaction takes place within a unit called electrolyser, which can range from small appliance-sized equipment well-suited for distributed hydrogen production to large-scale, central production facilities that can be connected directly to renewable or other zero-carbon electricity sources. Like fuel cells, electrolysers consist of an anode and a cathode separated by an electrolyte membrane.

Road Transportation

Road vehicles account for about 25% of global CO_2 emissions from energy and 75% of transportation specific emissions.[8] Efforts to decarbonise the sector have thus far largely focused on BEVs for the light-duty segment. Yet hydrogen-powered FCEVs also offer substantial promise.

[8] International Energy Agency (IEA), "Transport sector CO_2 emissions by mode in the Sustainable Development Scenario, 2000-2030", 22 November 2019.

FCEVs have significant advantages over BEVs in terms of refuelling times and driving ranges. Refuelling times are much shorter; filling current models takes less than five minutes and closely resembles the experience with a conventional vehicle.[9] In contrast, recharging a BEV can take anywhere from 20 minutes to 12 hours depending on the battery size, charger capacity, and depth of charge.[10] Driving ranges vary but tend to be similar to those of conventional vehicles (400-600 km).[11] Fuel cells also provide higher energy densities, lower weights and a lower material footprint compared to lithium batteries.[12] Given these benefits, FCEVs are ideally suited for end users who require low downtimes, drive long distances and carry heavy loads, such as taxis, buses, trucks and heavy-duty vehicles.[13]

However, widespread adoption of FCEVs is not as easy as it might seem; otherwise, they would already dominate battery-powered and ICE vehicles globally. There are significant issues hindering deployment at scale which need to be addressed.

First, fuel cells are more expensive than batteries and ICEs and, hence, less competitive due to higher total costs of vehicle ownership. Looking forward, for applications requiring fast fueling and high uptimes, analysts foresee light-duty FCEVs costs to be on par with those of conventional vehicles as soon as 2025.[14] For heavy-duty trucks, hydrogen could become competitive with diesel by 2031.[15]

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[9] U.S. Department of Energy, Energy Efficiency & Renewable Energy, "Alternative Fuels Data Center – Hydrogen Basics", 2020; N. De Blasio and F. Pflugmann, *Is China's Hydrogen Economy Coming? A Game-Changing Opportunity*, Harvard University, Belfer Center, July 2020.

[10] U.S. Department of Energy, "Vehicle Charging", 2020.

[11] J. Kurtz, S. Sprik, G. Saur, and S. Onorato, "Fuel Cell Electric Vehicle Driving and Fueling Behavior", National Renewable Energy Laboratory (NREL), March 2019.

[12] The Fuel Cell and Hydrogen Energy Association, Roadmap to a US Hydrogen Economy, 2020.

[13] J. Jones, A. Genovese, and A. Tob-Ogu, "Hydrogen vehicles in urban logistics: A total cost of ownership analysis and some policy implications", *Renew Sustain Energy Rev*, vol. 119, March 2020. https://doi.org/10.1016/j.rser.2019.109595.

[14] BloombergNEF, Hydrogen Economy Outlook, March 2020.

[15] Ibid.

Second, lack of enabling infrastructure remains a key barrier. Today, there are fewer than 1,000 hydrogen refuelling stations globally, compared to over 500,000 charge points for BEVs.[16] Furthermore, building a hydrogen fuelling station currently costs between US$1 and US$2 million,[17] compared to an estimated US$200,000 for an ultra-fast-charging electric-vehicle station with a single 350-kW charger.[18] Such investments are significant, particularly with so few vehicles operating; yet, a lack of refuelling infrastructure is often cited as the key obstacle to widespread adoption of FCEVs. Regardless, stakeholders around the globe are increasingly recognising hydrogen's promise for the sector, and China alone plans to invest US$17 billion in the FCEV industry through 2023.[19]

From a value chain perspective, FCEVs will complement, rather than compete with, BEVs and will be key in the decarbonisation of heavy-duty, long-distance applications, starting with captive fleets that require quick refuelling and high uptimes. Government support and public-private partnerships will be key to accelerate innovation cycles and the deployment of enabling infrastructure at scale.

Next Stop - Hydrogen Trains

Rail is one of the most energy-efficient and clean transport modes. Trains carry about 9% of global motorised passengers and 7% of freight, while accounting for only 3% of energy demand and 1% of CO_2 emissions of the overall transportation sector.[20]

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[16] IEA (2019).

[17] The International Council on Clean Transportation (ICCT), "Developing hydrogen fueling infrastructure for fuel cell vehicles", October 2017.

[18] R. Schreffler, "Costs Check Growth of Fuel-Cell Infrastructure", WardsAuto, 22 August 2019.

[19] Bloomberg, "China's Hydrogen Vehicle Dream Chased with $17 Billion of Funding", 2019.

[20] International Energy Agency (IEA), "Tracking Transport 2020", May 2020.

As old diesel trains are phased out from rail networks globally, hydrogen could become the answer to the complete decarbonisation of railway systems. Compared to other low-carbon alternatives such as electric trains, hydrogen offers greater flexibility and affordability, particularly over long distances and in rural areas.

Decarbonising rail systems remains difficult, nevertheless. In many countries, diesel trains still dominate. In 2018, among EU-28 countries,[21] nearly half of rail lines were still diesel-powered,[22] compared to the near totality of 26,000 freight and 431 passenger rail locomotives in the US.[23] So far, electrification has been the preferred option to decarbonise rail systems, but interest in hydrogen alternatives is rising, with over 22 demonstration projects across 14 countries[24] and a growing number of hydrogen train purchases.[25]

Cost is a key motivation. Hydrogen trains reduce emissions at a significantly lower cost than track electrification. While a new Alstom hydrogen-powered train can cost up to US$11 million,[26] an analysis of 20 railway lines in the UK and mainland Europe shows that the electrification of a single kilometre of track can cost upwards of US$1 million.[27] Even if hydrogen locomotives will require their own refuelling and servicing infrastructure, costs are likely to remain competitive because

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[21] Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden, United Kingdom (fmr member state).

[22] Statista Research Department, "Share of the rail network which was electrified in Europe by 2018, by country", *Statista*, 7 May 2021.

[23] U.S. Department of Transportation, Bureau of Transportation Statistics, "Rail Profile", 2020.

[24] Joint Fuel Cell and Hydrogen Undertaking, *Study on the use of fuel cells and hydrogen in the railway environment*, April 2019.

[25] M. Clemens, "Bourgogne-France-Comté opens the way for hydrogen trains in France", *Les Echos*, 5 March 2021.

[26] Alstom, "Alstom to supply Italy's first hydrogen trains", Press Release, 26 November 2020.

[27] Railway Industry Association, "RIA Electrification Cost Challenge", March 2019.

there is no need for track overhauls. This makes hydrogen trains particularly valuable in rural areas, where fewer passengers tend to travel longer distances.[28]

Another significant advantage of hydrogen-powered alternatives is their potential to serve as bi-mode trains, running on electrified and conventional lines alike. This option makes hydrogen trains a flexible alternative for decarbonising the sector while most tracks are not yet electrified. In addition, hydrogen trains are more resilient to network-wide disruptions, as a shared electric infrastructure means that any damage would impact all electric trains running on a given line. A hydrogen train could simply switch over to its fuel cell to produce the needed electricity.

Yet, hydrogen rail systems are not without challenges. Deploying the required infrastructure and hydrogen's lower volumetric energy density compared to diesel pose substantial barriers. Since freight is heavier than passenger transportation, hydrogen trains will require more fuel than diesel trains to serve the same routes. Therefore, innovation in more efficient ways to compress and store hydrogen will be needed to improve economics and scalability.

According to the *Road Map to a US Hydrogen Economy* report,[29] hydrogen could comprise 4% and 17% of the US rail market by 2030 and 2050, respectively. And several projects are already being piloted around the world, including HydroFLEX in the UK and Coradia iLint in Germany and Italy.

Shipping

Despite being one of the most efficient forms of freight transport, shipping remains a challenge for decarbonisation efforts. The sector accounts for about 3% of global and 11% of

[28] F. Zenith, R. Isaac, A. Hoffrichter, M. Thomassen, and S. Møller-Holst, "Techno-economic analysis of freight railway electrification by overhead line, hydrogen and batteries", *J Rail and Rapid Transit*, vol. 234, no. 7, 2020, pp. 791-802.

[29] The Fuel Cell and Hydrogen Energy Association (2020).

transportation-related CO_2 emissions, and has a self-imposed goal of reducing emissions by 50% by 2050 from 2008 levels.[30]

Thus far, electrification has been the preferred decarbonisation option. Battery-operated ships are already replacing vessels running on marine diesel oil (MDO) for short-distance operations like ferries.[31] But complete electrification remains a difficult value proposition due to the volume cargo operators would lose to store enough energy for long distance shipping. Large ships crossing oceans would simply need too many batteries. Hence, low-carbon fuels with high energy densities, such as hydrogen and ammonia, are expected to play a key role in the industry moving forward. On an energy content parity, while batteries require 64 times more volume than MDO, hydrogen and ammonia only require 8 and 3 times more, respectively.[32]

Ammonia, a hydrogen-based molecule, is a fuel that can either be combusted in an engine or used in a fuel cell. Liquid ammonia not only packs twice as much energy per volume as hydrogen but is also far easier to store because it needs simple refrigeration (-35°C) and not the cryogenic temperatures of hydrogen (-253°C). Furthermore, ammonia can also be converted back to hydrogen directly onboard, allowing operators to load and store ammonia but ultimately use it in a hydrogen fuel cell. However, ammonia is toxic to both humans and marine life; hence, safety and environmental hazards need careful evaluation and consideration.

Costs represent a critical factor as hydrogen-based fuels are still more expensive than conventional ones. In the case of ammonia, due to the added conversion steps, costs are even greater. Robust global hydrogen and ammonia networks to

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[30] International Maritime Organization (IMO), UN body adopts climate change strategy for shipping, 13 April 2018.

[31] Bastø Fosen, Verdens største elektriske bilferge i rutetrafikk på Oslofjorden (*The world's largest electric car ferry in scheduled traffic on the Oslo Fjord*), 2021.

[32] Amplifier, ETH zürich, SUS Lab Sustainability in Business Lab, "Towards Net-Zero: Innovating for a Carbon-free Future of Shipping in the North and Baltic Sea. DEEP-DIVE: Comparison of zero-carbon fuels", October 2019.

ensure that ships can refuel at any port will also be key to enable the sector's transition to a low-carbon economy. Policymakers will need to support innovation, deployment of enabling infrastructure at scale, and the definition of appropriate safety standards and regulations.

To date, over 140 companies have joined forces in the Getting to Zero Coalition,[33] which aims to achieve commercially viable zero-emission shipping by 2030. According to the International Council on Clean Transportation, liquid hydrogen could fuel up to 99% of existing interoceanic routes with the addition of a single refuelling stop.[34] And, as of 2020, more than 66 zero-emission shipping pilot projects have already been demonstrated worldwide.[35]

Hydrogen Powered Skies

Aviation, the fastest-growing transportation segment until 2019, is at a crossroads. Faced with the dual challenge of significant disruption to air travel due to the Covid-19 pandemic and growing pressure to curb emissions, the sector needs scalable decarbonisation pathways to reach net-zero emissions by 2050 in an environmentally and economically sustainable manner.[36]

In 2019, aviation accounted for around 3% of global energy-related CO_2 emissions and 12% of the transportation sector emissions.[37] This seemingly small number should not be dismissed, though, since the sector's overall contribution to global warming is significantly higher due to emissions other than CO_2, like nitrogen oxides and soot. Although the pandemic

[33] International Maritime Forum, *Getting to Zero Coalition*, 2021.

[34] The International Council on Clean Transportation (icct), https://theicct.org/marine.

[35] K. Sogaard and C. Bingham, "Mapping of zero emission pilots and demonstration projects", Global Maritime Forum, 27 August 2020.

[36] Air Transportation Action Group, https://www.atag.org/; Airlines4Europe (2021), "Destination 2050. A route to net zero European aviation", February 2021.

[37] International Energy Agency (IEA), *World Energy Outlook*, 2020; Air Transportation Action Group… cit.

has caused the largest retrenchment in the history of aviation, it also provides a unique opportunity for the sector to restructure itself toward a low-carbon future. Renewable fuels, including hydrogen, are poised to play a key role in this transition.

The advantages of hydrogen as an aviation fuel have been well-known for decades. Thanks to an energy density by mass three times higher than that of traditional jet fuel, liquid hydrogen has been the signature fuel for the American space program since the late 1950s. As a more scalable alternative to battery-powered aviation concepts, which present significant challenges, especially for larger aircraft applications due to energy density and safety considerations, hydrogen is now emerging as a significant component of commercial flights' future technology mix.

However, the road to hydrogen-powered aircrafts remains uncertain, and it will undoubtedly require significant efforts by all stakeholders to further invest in enabling technologies and the overall value chain. From an innovation perspective, the aviation industry will need to borrow technologies developed for the automotive and space industries and apply them to commercial aircraft operations, notably by bringing weight and costs down. One specific challenge will be how and where to store hydrogen onboard aircrafts while achieving similar or better safety targets than existing aircrafts. Beyond the technical aspects, this will require hydrogen-specific safety and regulatory standards that currently do not exist. Adoption of hydrogen at scale will also hinge on robust hydrogen fuelling infrastructure networks. While this challenge is daunting, with high fuel demand associated with airport operations, hydrogen could also be produced directly onsite, thereby eliminating distribution costs.

From a policy perspective, greater incentives for low-carbon aviation fuels, support for the development and deployment of enabling technologies and infrastructure, and the harmonisation of safety standards and regulations will be key in moving the needle on decarbonising aviation. Yet, due to very long aircraft development and certification lead times, these challenges demand urgent answers from both industry leaders and policymakers, who will need to keep up to date on the opportunities and barriers facing hydrogen-powered aviation, including public perception concerns.

Conclusion

Hydrogen must overcome significant barriers, mainly related to storage, infrastructure, and costs, before it can truly become a game changer in the transportation sector.

In road transportation, competitiveness will depend on overall costs of ownership and availability of refuelling infrastructure. Short refuelling times, lower added weight for stored energy, and zero tailpipe emissions are key advantages. Fuel cells also show promise thanks to their lower material footprint compared to lithium batteries. Long-distance and heavy-duty segments offer the greatest potential, but investments are required to lower the delivered price of hydrogen. Captive fleets can help to overcome the challenges of low utilisation of refuelling stations and spearhead the adoption of hydrogen.

In the rail sector, hydrogen trains could be most competitive in rail freight and rural/regional lines where long distances and low network utilisation do not justify the high costs associated with track electrification. Hydrogen trains also hold promise due to flexible bi-mode operations.

Shipping and aviation have limited low-carbon fuel options available and represent a significant opportunity for hydrogen-based fuels. In maritime applications, hydrogen and ammonia can overcome the limitations of battery ships and provide a route for meeting both national environmental ambitions and the sector's emission reduction targets. However, high costs compared to fossil fuels, the challenge of cargo volume loss due to fuel storage, and the deployment of global refuelling networks need to be addressed.

In the aviation sector, drop-in synthetic liquid fuels provide an attractive decarbonisation option at the expense of higher energy consumption and potentially higher costs. Direct hydrogen use also shows promise, but the sector will need to borrow technologies developed for the automotive and space industries and apply them to commercial aircraft operations, while achieving similar or better safety targets.

Overall, innovation will be crucial to reduce costs and improve performances of electrolysers, fuel cells, and hydrogen-based fuels. Technological challenges around weight and hydrogen storage need progress, particularly in the maritime and aviation sectors.

From a policy perspective, adoption at scale will require to:

- Establish a role for hydrogen in long-term domestic and international energy strategies, taking into consideration geopolitical and market implications.
- Implement policy support in the form of low-carbon targets and carbon pricing measures to stimulate commercial demand for clean hydrogen.
- Address investment risks, especially for first movers, such as targeted and time-limited loans and guarantees.
- Focus on new hydrogen applications, clean hydrogen supply and infrastructure projects.
- Support research and development efforts and public-private partnerships to accelerate innovation cycles.
- Harmonise standards and eliminate unnecessary regulatory barriers, while developing certification systems and regulations for carbon-free hydrogen supply.

To date, technological factors, economic considerations, and consumer choices have hindered the adoption of hydrogen at scale in the transportation sector. New geopolitical forces – such as the challenges of sustainable development and climate change – are reshaping the playing field. Stakeholders around the world will need to decide their role in this transition.

6.3 Towards a Carbon-Free Logistics

Alan McKinnon

As an economic activity, logistics has not commanded as much attention as manufacturing, retailing or finance. Consumers seldom spare a thought for the complex logistical systems that satisfy their material needs. For most businesses, it is an ancillary activity, typically accounting for a relatively small share of total expenditure, though providing a service vital for their survival and competitiveness. Logistics, by which I mean the movement, storage and handling of materials, is highly dispersed both organisationally and geographically and so tends not to be seen as an industry in its own right. Collectively, however, logistical activities account for around 12% of global GDP and a similar proportion of energy-related CO_2 emissions.[1]

This substantial carbon footprint has become a concern for governments and international organisations intent on levelling all sectors down to a net zero emission target by 2050. There is general recognition that the decarbonisation of logistics will be difficult, partly because the movement of goods is almost entirely powered by fossil fuel but also because the demand for freight transport is forecast to rise steeply over the next few decades. Shipping, air cargo and long haul trucking are seen as being particularly "hard-to-abate" sectors and they account for around 85% of all freight movement.[2] [3] Warehousing and terminal operations, on the other hand, will directly benefit from the decarbonisation of electricity grids and have the potential to micro-generate renewable energy on-site. These operations, however, are only responsible for around 11-13% for total logistics CO_2 emissions.[4]

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[1] T. Maiden, "How big is the logistics industry", FreightWaves, 11 January 2020; Smart Freight Centre, *Smart Freight Centre Annual Report 2019*, Amsterdam, 2020.

[2] Assuming that 80% of road freight is non-urban.

[3] International Transport Forum, ITF Transport Outlook 2019, OECD, Paris, 2019.

[4] A.C. McKinnon, *Decarbonizing Logistics: Distributing Goods in a Low Carbon World*,

Logistics can be decarbonised in many different ways, most of them mutually reinforcing. It will require aggressive, co-ordinated and time-phased application of a broad range of technical, operational, managerial, behavioural and policy measures to get logistic emissions down to 2030 and 2050 levels consistent with a 1.5oC limit on global warming since pre-industrial times. These measures fall into five general categories, which may be considered decarbonisation "levers":

1. Restraining the demand for freight transport;
2. Shifting freight to lower carbon transport modes;
3. Optimising the utilisation of freight carrying capacity;
4. Improving the energy efficiency of logistics;
5. Repowering logistics with low carbon energy.

The first two sets of options correspond directly to the Avoid and Shift categories in the much-cited ASI framework. In analysing the potential for decarbonising logistics, it is helpful to split the Improve category in this framework into three separate sets of initiatives. Much attention is currently focused on the fifth set in the hope that new technology will facilitate the transition from fossil to renewable energy in the logistics sector. By reducing GHG (greenhouse gas) emissions per tonne-km of freight movement and per unit of warehouse throughput, this would ease the pressure on the other four decarbonisation levers.

There are wide variations in the rate at which the five sets of decarbonisation initiative can be applied at scale. "De-fossilising" fleets of trucks, locomotives, ships and planes is a medium-to-long term ambition. This is partly because these fleets have a long asset-life and opportunities for switching existing fleets to low carbon energy are limited. It will also take time to build up mass-production of affordable non-fossil vehicles and to establish renewable energy supply systems at scale. Many of the managerial and behavioural options in categories 1-4, on the other hand, can deliver sizable carbon

London, Kogan Page, 2018.

reductions relatively quickly. Given the urgency and extent of the required emissions reductions, the contribution of these options will be critical over the decade. In combination they can substantially decrease the total amount of logistics energy that will need to be switched to renewable sources in the longer term.

There is also a strong financial case for prioritising options in the first four categories because many of them have low, and often negative, carbon mitigation costs. In a recent survey of over ninety European logistics executives, 40% claimed that a half or more of CO_2-reducing measures in logistics also yield cost savings.[5] In their estimation, the most cost-effective measures were those which shifted freight to lower carbon transport modes (category 2) and improved vehicle loading (category 3). Many of the efforts to increase the energy efficiency of freight transport and warehousing (category 4) are also deemed to be "low hanging fruit", often justifiable on purely commercial grounds and involving relatively modest capital expenditure. In contrast, the transformation of vehicle fleets and transport/ energy infrastructure for the switch to renewable energy will entail substantial capital investment with lengthy pay-back periods.

Decarbonisation levers 2 to 5 reduce the carbon intensity of logistics. Even optimistic projections of the decline in the average carbon intensity of freight transport will still leave it emitting around 3 Gtonnes of CO_2 in 2050.[6] In its high-ambition scenario, the ITF envisages the average carbon intensity of freight transport worldwide by all modes plunging from 24 gCO_2 per tonne-km in 2015 to 9 gCO_2 per tonne-km in 2050, but total CO_2 emissions would still rise by a fifth. This because the ITF also anticipates a 3.3 times increase in the level of freight movement between 2015 and 2050, which would

[5] A.C. McKinnon M. and Petersen, *Measuring Industry's Temperature: An Environmental Progress Report on European Logistics*, Center for Sustainable Logistics and Supply Chains, Kühne Logistics University, Hamburg, 2021.
[6] *ITF Transport Outlook 2019*…, cit.

more than offset the dramatic drop in carbon intensity. Serious thought must therefore be given to the first decarbonisation lever, which restrains the growth in demand for freight movement and may eventually need to reverse it.

Getting the decarbonisation of logistics cost-effectively onto a trajectory that will meet near-term as well as long-term carbon reduction targets will therefore require full deployment of all five categories of initiatives. The remainder of this paper examines each of these categories (or levers) in turn, briefly discussing the contribution they can make.

Restraining the Demand for Freight Transport

This is politically the most sensitive of the five sets of decarbonisation options. There has traditionally been a close correlation between the growth of freight tonne-kms and the growth of GDP. Governments therefore fear that policies to control freight traffic growth may also inhibit future economic development. While pursuit of net-zero targets may ultimately force politicians to accept that indefinite economic expansion is unsustainable, few governments are yet prepared to concede that the time has come to curb the growth of freight traffic. Nevertheless, in some wealthier countries, tonne-kms have been growing more slowly than GDP, mainly as a result of the off-shoring of manufacturing to low labour-cost countries and the service sector markedly increasing its share of GDP.[7] Internationally, the so-called trade multiplier (the ratio of trade growth to global GDP growth) has also dropped sharply over the past fifteen years to almost parity. This might suggest that the average freight transport intensity of the global economy, which rose sharply during the peak years of globalisation, has stabilised. Trade and GDP, however, are monetary variables and do not

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[7] A.C. McKinnon, "Decoupling of Road Freight Transport and Economic Growth Trends in the UK: An Exploratory Analysis", *Transport Reviews*, vol. 27, no. 1, 2007, pp. 37-64.

translate directly in physical flows of freight. A pre-pandemic forecast suggested that globally the amount of freight movement would increase at an annual compound rate of 3.1% between 2015 and 2030 and 3.4% over the following twenty years.[8]

In the absence of policy initiatives explicitly designed to constrain or reverse freight traffic growth, a number of technological, business and consumer trends may independently have this effect. Of the Industry 4.0 technologies, further digitisation of news, entertainment and educational media and additive manufacturing/3D printing may help to dampen freight demand. By shortening and streamlining supply chains 3D printing could substantially cut tonne-kms,[9] though it may not promote as much reshoring of production operations as had been expected.[10] Downsizing and lightweighting of products and a greater willingness by consumers to share rather than own goods (such as autonomous vehicles) could also help to reduce the amount of stuff to be moved. Increasing the circularity of the global economy promoting greater re-use, remanufacturing and recycling of materials and the suppression of waste would have a similar effect. It has been estimated that full application of the principles of economic circularity could cut GHG emissions by 40%, partly by the rationalisation of logistics.[11] The phasing out of fossil fuels over the next few decades will sharply reduce the movement of coal, oil and gas. On the other hand, the replacement of the current fossil fuel supply system with a renewable energy infrastructure is already generating substantial volumes of freight traffic, though once this infrastructure is in place energy-related freight movement will be much reduced. Finally, recent surveys suggest[12] that in

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[8] *ITF Transport Outlook 2019*…, cit.

[9] A.C. McKinnon (2018).

[10] C. Freund, A. Mulabdic and M. Ruta, *Is 3D Printing a Threat to Global Trade?*, Policy Research Working Paper 9024, World Bank Group, Washington DC, 2020.

[11] Ellen MacArthur Foundation / Material Economics, *Completing The Picture How The Circular Economy Tackles Climate Change*, 26 September 2019.

[12] See *Fast forward: rethinking supply chain resilience in a post-Covid19 world*, Capgemini

the post-Covid world companies will prioritise resilience in the management of their supply chains, a trend which may favour more localised sourcing.

Climate policy could try to reverse the two spatial processes that have driven much of the past growth in freight movement, namely the wider sourcing of supplies and the centralisation of production and inventory. Pursuing a relocalisation strategy would cut freight-related emissions but could increase total life cycle emissions for some categories of product. This is because freight movement typically constitutes a small proportion of total life cycle emissions and any reduction in these emissions from localisation can be small relative to geographical differences in the carbon intensity of production operations. Moreover, the economic benefits of much international trade have been found to exceed the related environmental costs even with carbon prices pitched at relatively high level.[13] Decentralising production and inventory could also reduce the freight transport intensity of economies but at a comparatively high carbon mitigation cost. Economies of scale in manufacturing and warehousing would be lost, inventory levels would rise in accordance with the so-called "square root law of inventory" and substantial capital investment would be required in a new generation of more localised facilities.[14,15] Fairly draconian fiscal and regulatory policies would be needed to induce companies to reverse many decades of production and inventory centralisation at national, continental and global levels.

Research Institute, 2021.

[13] J.S. Shapiro, "Trade costs, CO_2 and the environment", *American Economic Journal*, vol. 8, no. 4, 2016.

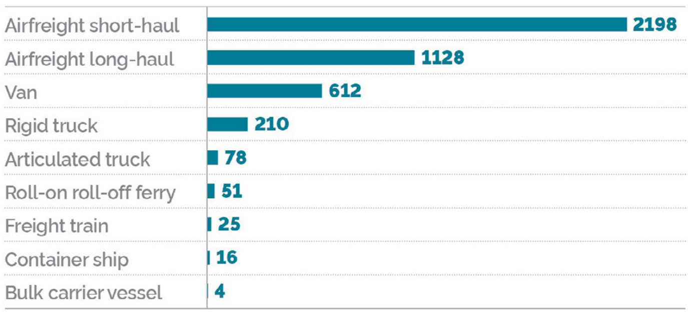
[14] Constructing these facilities would also carry a significant carbon penalty.

[15] A.C. McKinnon (2018).

Shifting Freight to Lower Carbon Transport Modes

Freight transport modes vary enormously in their average carbon intensity (Figure 1). It is understandable therefore that public policy-makers have traditionally seen freight modal split as one of the main ways of decarbonising freight transport. For example, it is central to the EU's new Smart and Sustainable Mobility Strategy.[16] The potential for shifting express freight from planes to ships at an inter-continental scale is considered to be very limited, though significant amounts of air cargo have recently transferred to trans-Asian rail freight services, admittedly from a very low base.

FIG. 1 - VARIATION IN THE CARBON INTENSITY OF FREIGHT TRANSPORT MODES (CO_{2E} PER TONNE-KM)



Source: DBEIS / DEFRA, "UK Government GHG Conversion Factors for Company Reporting", Department for Business Energy and Industrial Strategy and Department of the Environment, Food and Rural Affairs, London, 2020

The main focus of modal shift efforts is at national and intra-continental levels, where the objective is to get as much freight as possible off trucks and onto trains, barges and coastal shipping. In most cases this requires the reversal of a long-term erosion of freight from rail to road networks, a process

[16] European Commission, "Sustainable and Smart Mobility Strategy", 2020.

that very few countries to have ever managed to achieve. Road haulage exerts a tight grip on the freight market in many countries, particularly those whose size and industrial geography prevents the railway from exploiting its competitive advantage in long haul, bulk movement. The gravitation of factories and warehouses to points of high accessibility on the highway network and wide adoption of just-in-time replenishment has effectively locked many companies' logistics systems into heavy reliance on road. It is ironic too that the low-carbon rail and water-borne freight modes are currently losing much of the fossil fuel traffic that for generations has been a core business. Replacing billions of tonne-kms of coal, oil and gas traffic with flows of other lighter, higher-value, time-sensitive manufactured goods will be a big challenge. The public policy expectation, however, is that these greener modes will go well beyond fossil-fuel substitution and greatly increase their overall share of the freight market. The prospects of this happening and freight modal shift delivering the targeted levels of carbon savings will depend on several factors. First is the willingness of businesses to review their modal options and adopt a multi-modal strategy. It is encouraging that industry attitudes, which were often dismissive of modal shift, appear to be changing. The survey of European logistics executives mentioned earlier actually rated modal shift as the most cost-effective way of decarbonising logistics operations.[17] In many countries, however, the operational efficiency and quality of rail and waterborne services will need to be substantially upgraded to meet the logistical requirements of a more diverse and demanding customer base. This requires, among other things, a mix of infrastructural investment, changes to working practices, cross-border inter-operability and digitalisation. It also requires fuller exploitation of intermodality to lure onto the rail and waterway networks more freight moving to and from industrial premises without direct access to either network. In China, the

[17] A.C. McKinnon and M. Petersen (2021).

EU, India, Mexico and other countries intermodal services are being heavily promoted along strategic corridors within which investment in routes and terminals is being concentrated.[18]

A fundamental reallocation of freight between transport modes will require more than technical upgrades. They will need to be supplemented with managerial and fiscal changes. One such managerial change involves applying the concept of synchromodality to the scheduling of different freight transport modes to minimise delays at modal transfer points.[19] It can also involve integrating modal selection into production planning and inventory management in a way that has been shown to cut both cost and CO_2 emissions by significant margins where the conditions are right.[20] A fiscal policy long advocated as a freight modal split game-changer is the internalisation of environmental costs in higher taxes. The inclusion of freight transport in emission trading or carbon taxation schemes would also favour cleaner, lower carbon modes.

Optimising the Utilisation of Freight Carrying Capacity

Across all transport modes, available carrying capacity is seriously under-used. As a result the ratio of vehicle-kms to tonne-kms is much higher than it needs to be. If trucks, trains, ships and planes were better filled, traffic levels, energy consumption and emissions could all be significantly reduced. It is difficult to estimate at a global level the potential carbon savings from improved loading as very few countries collect freight transport

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[18] L.H. Kaack, P. Vaishnav, M.G. Morgan, I.L Azevedo, and R. Srijana, "Decarbonizing intraregional freight systems with a focus on modal shift", *Environmental Research Letters*, vol. 13, no. 8, 2018, pp. 1-29.

[19] L. Tavasszy, B. Behdani, and R. Konings, *Intermodality and synchromodality*, SSRN, 2015.

[20] C. Dong, R. Boute, A.C. McKinnon, and M. Verelst, "'Investigating synchromodality from a supply chain perspective' Transportation Research Part D", *Transport and Environment*, vol. 61, 2018, pp. 42-57.

utilisation data.[21] However, the available macro-level statistics suggest that on average between a quarter and a third of truck-kms are run empty and 40% or more of carrying capacity on laden truck trips is unused. This latter statistic is particularly difficult to quantify because capacity utilisation needs to be measured in both weight and volumetric terms, with account taken of the density of the commodities being transported. Most of the currently available data measures load factors purely in weight terms, ignoring the fact that loads of low density products "cube-out" long before they "weight-out". Composite indices are needed to give a true picture of capacity utilisation, as used by companies such as Procter & Gamble, but there is little prospect of such metrics being adopted by government freight surveys in the near future.

While the statistical evidence is patchy, there is a general consensus that better loading of vehicles could make a major contribution to the decarbonisation of logistics. It should be noted too that, in this context, "better" does not always mean "higher". Many trucks, particularly in less developed countries, are seriously over-loaded. This can also carry a net carbon penalty where a "labouring" engine consumes more fuel and damage is done to the road surface which thereafter prevents all categories of traffic from running at their most fuel-efficient speed. In developing countries, tighter enforcement of vehicle weight restrictions and higher penalties for infringement are required to suppress high levels of over-loading, not just to cut carbon emissions but also to protect transport infrastructure, improve safety and correct market distortions.

While over-loading breaks the law and demands a public policy response, under-loading is not illegal and needs to be addressed primarily by businesses. One might expect companies to be strongly motivated to keep vehicles well-filled for purely commercial reasons. So why is there so much empty running and under-loading across the freight sector? I answer this

[21] A.C. McKinnon (2018).

question more much fully elsewhere,[22] but the main constraints on loading can be summarised as volatility in the demand for freight services, geographical imbalances in the pattern of traffic flow, a lack of information about potential load-matches, product handling characteristics, vehicle size and weight limits, poor co-ordination transport and procurement operations and a willingness to trade-off lower vehicle utilisation for other logistical and marketing benefits. The main example of such a trade-off is just-in-time (JIT) replenishment, which often involves companies sacrificing transport efficiency in order to minimise inventory and improve the productivity of manufacturing operations. Such trade-offs are economically rational but may need to that the JIT principle should be abandoned, as some environmentalists have suggested. This would undoubtedly cut the carbon intensity of deliveries but often at the expense of higher energy consumption and emissions in production and warehousing operations. So, a holistic assessment of the carbon impact of relaxing JIT replenishment is needed before this is widely promoted as a carbon mitigation measure.

In the meantime, several other developments are likely to raise vehicle load factors. Online load matching services, which have now been in existence for over 20 years, are being transformed by a new wave of digital innovation, using big data, predictive analytics and machine-learning to raise levels of capacity utilisation. After decades of debate, supply chain collaboration is finally gathering momentum, particularly its "horizontal" type involving companies, sometimes competitors, at the same level in the supply chain sharing their logistics assets.[23] In the longer term, the creation of a physical internet, replicating key characteristics of the digital internet

[22] Ibid.; and A.C. McKinnon, "Maximizing capacity utilization in freight transport", in E. Sweeney and D. Waters (Eds.), *Global Logistics: New Directions in Supply Chain Management*, 8th edition, London, Kogan Page, 2021.

[23] F. Cruijssen, *Cross-chain collaboration in logistics: looking back and ahead*, Cham, Springer, 2020.

such as open systems, shared networking and modularisation in the tangible world of logistics, could bring a step change in asset utilisation and carbon efficiency.[24] Regulatory change, particularly in EU Member States such as the Netherlands, Denmark, Finland and Spain, has relaxed truck size and weight constraints, permitting greater load consolidation. This move to high capacity transport (HCT) has been shown to yield net reductions in CO_2 emissions, even after allowance is made for any second-order modal shift and induced traffic effects.[25]

Improving the Energy Efficiency of Logistics

Around 90% of the energy used in logistics moves freight, while most of the remainder is consumed by its handling, transhipment and storage in terminals and warehouses. The energy efficiency of both vehicles and buildings has been improving, though the potential exists to accelerate this rate of improvement with a combination of technical and operational initiatives. Tightening fuel economy standards for new trucks and new ships are exerting regulatory pressure on vehicle manufacturers and ship builders to develop and apply fuel-saving technologies. Over 70% of new trucks and 85% of new vans are now sold in countries with fuel economy standards in place.[26] For example, the EU decrees that the carbon efficiency of new trucks must rise by 15% between 2019 and 2025 and 30% by 2030. In accordance with its EEDI system, the International Maritime Organisation (IMO) will require new ships coming into service after 2025 to be at least 30% more

[24] E. Ballot, M. Russell, and B. Montreuil, *The Physical Internet: the Network of Logistics Networks*, Paris, PREDIT, 2014, p. 4; ALICE, "A framework and process for the development of a roadmap towards zero emissions logistics 2050", Alliance for Logistics Innovation through Collaboration in Europe, Brussels, 2019.

[25] International Transport Forum, *High Capacity Transport: Towards Efficient, Safe and Sustainable Road Freight*, Case-Specific Policy Analysis, OECD, Paris, 2019.

[26] International Energy Agency (IEA), *Trucks and Buses*, Tracking Report, Paris, June 2020.

energy efficiency than the average vessel built between 2000 and 2010 (International Maritime Organisation, 2020). Although the energy efficiency of new locomotives and planes is not governed by similar regulations, the overall fuel efficiency of rail freight and air cargo operations is also projected to increase over the next few decades.[27] A broad range of energy-saving technologies can be applied across all types of freight vehicle and logistics building both at the time of construction and with subsequent retrofitting.

Technical enhancements to the energy efficiency of logistics can be augmented by a range of operational and behavioural measures, many of which can be implemented in the short- to medium-term with minimal capital investment. One such measure is training truck drivers to drive more fuel efficiently, monitoring their subsequent driving behaviour and, where necessary, providing additional guidance and encouragement. This can offer average fuel and CO_2 savings of 5-10%.[28] Another managerial measure that has been shown to yield significant fuel savings in the road freight sector is the rescheduling of deliveries to the evening or night when traffic levels are relatively low and vehicles can travel at more fuel-efficient speeds.[29] As road networks become more congested and more industrial, and as commercial premises move to 24 hour operation, the business and carbon cases for such rescheduling strengthen. Speed reductions have also been shown to be an effective means of cutting energy consumption and emissions,[30] although

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[27] International Energy Agency (IEA), *The Future of Rail. Opportunities for energy and the environment*, Technology Report, IEA and UIC, Paris, January 2019; International Civil Aviation Organisation (ICAO), *Envisioning a "zero climate impact" international aviation pathway towards 2050*, Working Paper/561, Montreal, 2019.

[28] AECOM, *Eco-Driving for HGVs*, Final Report, London, Department for Transport, December 2016.

[29] J. Holguín-Veras, T. Encarnación, C.A. González-Calderón, J. Winebrake, C. Wang, S. Kyle, and R. Garrido, "'Direct impacts of off-hour deliveries on urban freight emissions', Transportation Research Part D", *Transport and Environment*, vol. 61, Part A, 2018, pp. 84-103

[30] A.C. McKinnon, "Freight Transport Deceleration: Its Possible Contribution

this challenges the widely-held view in logistics that progress means moving goods faster. The 4th Greenhouse Gas study of the IMO acknowledges that "*operating speeds remain a key driver of trends in emissions and rate of emissions growth*".[31] "Slow steaming", which has been widely adopted by shipping lines over the past fifteen years primarily for commercial reasons, has cut CO_2 emissions by a significant margin.[32]

Like initiatives to improve capacity utilisation, fuel saving measures can often be justified solely on economic grounds and so can have a negative carbon mitigation cost. The net mitigation cost, however, depends on the prevailing price of the fuel. Unfortunately, diesel and petrol prices are held artificially low in many countries by government subsidies, discouraging operators from investing in fuel-saving devices and practices. The phasing-out of these subsidises and their replacement with taxes on fossil-fuel consumption would strongly incentivise the adoption of fuel economy measures. Fiscal levers can also be supplemented by government advisory schemes, particularly as the road haulage sector in most countries is highly fragmented and composed of small carriers who often lack the knowledge and skills to cut fuel use and emissions.[33] As many of these carriers now work on a sub-contract basis for larger logistics service providers (LSPs), these LSPs have an important role to play in disseminating good practice in energy efficiency. They have a vested interest in doing so because these carriers' carbon emissions fall within the boundary of the LSPs' Scope 3 emission reduction targets.

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to the Decarbonisation of Logistics", *Transport Reviews*, vol. 36, no. 4, 2016, pp. 418-436.

[31] J. Faber et al., *Reduction of GHG emissions from ships: Fourth IMO GHG Study 2020. Final report*, International Maritime Organisation, London, 2020.

[32] M. Acciaro and A.C. McKinnon, "Carbon emissions from container shipping: an analysis of new empirical evidence", *International Journal of Transport Economics*, vol. 42, no. 2, 2015, pp. 211-228.

[33] M. Toelke and A.C. McKinnon, *Decarbonizing the operations of small and medium-sized road carriers in Europe: An analysis of their perspectives, motives, and challenges*, Smart Freight Centre, Amsterdam, 2021.

Repowering Logistics with Low Carbon Energy

The previous four categories of initiative in combination could substantially reduce the carbon intensity of logistics, but not get it down to zero. The EU target of a 90% reduction in transport-related CO_2 emissions by 2050 would also be unattainable without this fifth decarbonisation lever – "defossilising" the energy used in logistics. This is often seen as the main method of decarbonising logistics, because it deals with the climate change problem at source, i.e. the burning of fossil fuel, offers the prospect of complete decarbonisation and eases the pressure on companies to fundamentally change the way they manage their logistics systems and supply chains. As explained at the start, however, these managerial changes will be required to meet near-term carbon reduction targets and reduce the total amount of logistic energy that will need to be switched to renewable energy in the long run.

For land-based logistics this switch will primarily involve electrification and reliance on the decarbonisation of grid electricity. The average carbon intensity of electricity worldwide is predicted to drop by a third between 2018 and 2040, but could fall by as much as 80% if the IEA's "sustainable development" scenario were to be realised.[34] Logistics operations currently powered by electricity- around 50% of rail freight movements worldwide, almost all warehousing and terminal activities and an increasing proportion of local, battery-powered deliveries – will directly benefit from this trend. Many warehouses, freight terminals and ports will be able to supplement or replace low carbon grid electricity with the on-site micro-generation of zero carbon electricity using wind turbines and/or solar panels. Some distribution centres with roofs covered by solar panels have already become carbon negative, feeding excess zero-carbon electricity into the grid.

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[34] International Energy Agency (IEA), Tracking Power 2020, Tracking Report, IEA, Paris, June 2020.

An increasing proportion of the global rail network is being electrified, while in some places where there are few if any electrified lines, as in North America, battery- and hydrogen-powered locomotives are being trialled as alternative means of getting low carbon electricity into the rail freight system. Battery-electrification of local road deliveries by vans and small rigid vehicles is well underway, with the total cost of ownership of some electric vehicles now comparable to those vehicles powered by diesel or petrol.[35]

There is much more debate over the choice of low carbon powertrains for heavier, long haul trucks. This choice is mainly between batteries, hydrogen fuel cells, highway electrification and biofuel.[36] It is likely that all four will contribute to the decarbonisation of long haul trucking but in proportions varying by country and freight market sector. In smaller countries where delivery distances are relatively short, battery-powered trucks will cater for most non-urban duty cycles. The traditional view that batteries for long haul trucks would be too heavy, take too long to recharge and be too expensive has had to be revised in the light of recent advances in battery technology and vehicle design. Highway electrification using catenary systems, such as those being trialled in Sweden, Germany and California, may be a cost-effective means of decarbonising long haul trucking in larger countries.[37] Hydrogen fuel-cell vehicles will have a greater distance range and offer faster refuelling, but will only become low carbon when adequate supplies of green hydrogen, produced by electrolysing water with decarbonised electricity, become available, whenever that might be. The energy "supply

[35] CE Delft, *Van use in Europe and their environmental impact*, Report for Transport and Environment (T&E), Delft, 2017.

[36] Energy Transitions Commission, *Mission Possible*, Sectoral focus – heavy road transport, 2019; J. Neuhausen, C. Foltz, P. Rose, and F. Andre, *Truck Study 2020. Making zero-emission trucking a reality*, Strategy&, 2020; Shell/Deloitte, "Decarbonising Road Freight: Getting into Gear", 2021.

[37] F. Unterlohner "How to decarbonise long-haul trucking in Germany. An analysis of available vehicle technologies and their associated costs", Transport & Environment, Brussels, April 2021.

chain" for green hydrogen is also very energy-intensive, leading some specialists to conclude that it should be reserved for other transport modes and industrial processes that are much harder to decarbonise by other means.

Biofuels can also play a transitional role in the decarbonisation of trucking, though only those which offer a significant reduction in GHGs on a so-called well-to-wheel (WTW) basis. Impressive tank-to-wheel CO_2 savings are often claimed for the use of biofuels in trucks relative to diesel though life-cycle analysis can reveal relatively high levels of GHG emissions upstream of the vehicle fuel tank depending on the nature and source of the feedstock.[38] For example, the use of recycled cooking oil to make hydro-treated vegetable oil (HVO) or the anaerobic digestion of food waste to produce biomethane can significantly reduce GHG emissions on a WTW basis whereas biodiesel made with palm oil originating from tropical plantations is generally much worse than conventional diesel in carbon terms. Limited supplies of sustainable feedstocks will limit the scalability of biofuel pathways to truck decarbonisation, leaving low carbon electrification as a much more realistic long-term option.

The movement of freight by sea or air offers limited scope for electrification and presents much greater decarbonisation challenges. Large-scale electrification of cargo vessels and aviation seems a distant prospect. The capacity and performance of marine batteries are steadily improving and their cost per kWh reducing, though their application is likely to remain limited to short-distance RoRo ferry and barge operations. Onboard wind-generated electrical power will help to reduce the carbon intensity of shipping, but only at the margins. There are, in fact, no easy low carbon energy options for shipping, the mode that accounted for around 70% of all freight tonne-kms in 2015.[39] Ammonia and biofuels, such as biomethanol and bio-

[38] Ecofys, IIASA and E4Techn, *The Land Use Change Impact of Biofuels Consumed in the EU Quantification of Area and Greenhouse Gas Impacts,* Study commissioned and funded by the European Commission, 27 August 2015.

[39] *ITF Transport Outlook 2019*…, cit.

LNG, are currently being evaluated as low carbon alternatives to the heavy fuel oil (HFO) and marine diesel which currently power global shipping,[40] though producing them at sufficient scale will require an enormous capital investment and raise other environmental, safety and land-use issues.

The very low energy density of batteries relative to that of kerosene constrains the electrification of aviation, though some researchers suggest that this may be feasible by the 2040s. Airbus plans to launch a net zero aircraft by 2035, powered by hydrogen, either directly or in a synthetic fuel.[41] It is not known how long it would take such technology, being developed primarily for passenger aviation, to impact on the global air cargo market. As around 50% of air freight currently moves in the "bellyholds" of passenger aircraft, there are likely to be synergies in the decarbonisation of personal and freight movement by air. Waste material is also being used to produce biofuel with a low GHG content for jet aircraft. The use of biofuel, made either from waste or biomass, to decarbonise aviation would, however, require a huge investment in refining capacity – in up to 170 new bio-refineries every year till 2050, according to the International Civil Aviation Organisation (2016).[42]

Conclusion

The path to zero carbon logistics is paved with a rich assortment of decarbonisation measures. Many of those in the first stretch represent "low hanging fruit" and are already being exploited. They comprise a mix of technical, behavioural and managerial changes, many of the latter being facilitated by the rapid and

[40] H. Xing, C. Stuart, S. Spence, and H. Chen, "Alternative fuel options for low carbon maritime transportation: pathways to 2050", *Journal of Cleaner Production*, vol. 297, 15 May 2021.

[41] N Potter, "Airbus Plans Hydrogen-powered Carbon-neutral Plane by 2035. Can they work?", *IEEE Spectrum*, 12 October 2020.

[42] International Civil Aviation Organisation (ICAO), *On Board: A Sustainable Future*, ICAO Environmental Report 2016, Montreal, 2016.

extensive digitalisation of logistics. In addition to having low or negative carbon mitigation costs, these initiatives have the potential to cut emissions in the short to medium term. Further along the path, capital investment requirements and carbon mitigation costs will rise as decarbonisation becomes driven primarily by the transitioning of freight transport fleets from fossil to renewable energy. As pressure mounts to achieve deep carbon reductions rapidly, the uptake of more costly and disruptive changes may have to be hastened by tougher fiscal and regulatory policies. This may include policies to depress the demand for freight transport if it becomes apparent that sharp reductions in the carbon intensity of freight transport are failing to get logistics onto a zero-emission trajectory. By then, however, adaptation to climate change and GHG sequestration in pursuit of "net-zero" may be generating a new wave of logistical activity not currently factored into long-term freight decarbonisation models.

6.4 What Comes Next for Rail Infrastructure Investments?

Gianluigi Vittorio Castelli, Valerio Pieri

The mobility of people and goods is an essential factor for economic and social development. On the one hand, the availability of transport infrastructures increases the attractiveness and competitiveness of territories and engenders a virtuous process of development and growth. On the other hand, poorly connected territories follow a path of decline, impoverishment and depopulation.

The current mobility model, based on fossil fuel-powered vehicles, has effectively supported the extraordinary growth of one part of the world, the West and a few other countries, for nearly two centuries. It worked fine 100 years ago, when the world population was less than 2 billion people and most of the countries in the world were excluded from industrialisation and economic development.

As the number of countries where industry and service sectors grows, boosting incomes, wealth and welfare, our conventional mobility model is proving more and more unsustainable. The planet has proved to be unable to bear the emissions of almost 8 billion inhabitants (with growth prospects of up to 9 billion by 2040 and 10 billion by 2060) who travel and move their goods on fossil-fuel vehicles – at least without dramatic, and probably fatal, repercussions.

In the latest breakdown of global emissions by sector, published by Climate Watch and the World Resources Institute (2018), direct greenhouse gas (GHG) emissions (including non-CO_2 gases) from transport are estimated at around 8.3 gigatonnes of CO_2 equivalents ($GtCO_2eq$), equal to almost one-sixth of global emissions. This figure does not include emissions from the production of motor vehicles and other transport equipment, which are included in the "energy use in industry" subsector.

Transport is therefore one of the priority areas of intervention for decarbonisation, presenting a twofold, pressing challenge. On the one hand, transport infrastructures should continue to grow, linking more and more territories and communities, facilitating the spread of economic and social well-being through increased mobility. Conversely, as our carbon budget rapidly shrinks, we must urgently break the correlation between economic growth and the increase of transport emissions, by inventing and implementing brand-new mobility models with a minimal environmental impact, especially in terms of GHGs emissions. The transport section of the reports of the Intergovernmental Panel on Climate Change (IPCC) may be referred to for the most authoritative and referenced summary of the many issues at stake and the main possible mitigation and adaptation strategies. At the time of writing this paper, the IPCC Sixth Assessment Report (AR6) is about to be published.

The most developed countries must take greater responsibility and be pioneers of change, supporting, with courage and by any means necessary, the efforts necessary to make the transition towards new models of sustainable mobility.

Bearing in mind that there are significant regional differences in transport mitigation pathways, the following paragraphs will present some short remarks on the evolution of rail infrastructure investments in Europe.

After a brief overview of the strategic role of railways for the decarbonisation of the transport sector and of the unprecedented public and private financial support currently enjoyed by rail investments in Europe (second paragraph), the paper focuses on the major objectives of railway investments (third paragraph) and on three fundamental enablers, namely the capacity of defining and agreeing upon a long-term strategic vision for the transport system, the spread of a mature and conscious approach to innovation and the quality of the investment governance system (fourth paragraph).

An Unprecedented Political and Financial Support for Modal Shift

In Europe, just 8% of people and less than 18% of goods travel by train (Eurostat, latest data available). These percentages are essentially unchanged over the last 15 years, in spite of the fact that modal shift has been an objective of the European political agenda since the 1990s.

In all short and medium-term scenarios, rail transport is the cleanest and safest means of transport available. While it may sound strange, a means of transport that is 200 years old will play a crucial role in the future mobility system.

The latest data published by the European Environment Agency show that, in Europe, 22% of total EU-27 GHG emissions come from road transportation, with railways accounting for less than 1% (year 2018).

Rail transport generates, on average, much lower emissions than road transport. According to data published by CER (cer.be/topics/sustainability), if rail and road CO_2 emissions are compared, the ratio in favour of rail is 1 to 4 for passenger transportation (28g vs. 102g CO_2 per passenger-kilometre, i.e. to transport one passenger over one kilometre) and 1 to 9 for freight transportation (16g vs. 140g CO_2 per tonne-kilometre, i.e. to transport one tonne of goods over a distance of one kilometre). Rail is also six times more energy-efficient than road, thanks to physical advantages such as lower rolling and air resistance.

It is clear that an extraordinary cut in emissions could be obtained by shifting a significant share of people and goods from road to rail.

The modal shift would improve the quality of the transport system, helping to decongest roads and increase safety (especially by reducing the traffic of heavy vehicles, which still carry over 75% of goods in Europe).

For these reasons, as extensively argued in the recently published "Sustainable and Smart Mobility Strategy", the European Commission has included modal shift among its priority strategies. The European Green Deal calls for a 90% reduction in greenhouse gas emissions from transport, in order for the EU to become a climate-neutral economy by 2050, while also working towards a zero-pollution target.

The European Parliament officially declared that year 2021 is the European Year of Railway Transport, and, in fact, rail transport is experiencing unprecedented political and financial support by the European institutions. Not only has a plan of regulatory interventions been set out, but massive public financial resources will also fund rail infrastructure investments in the next years.

Furthermore, railway operations are particularly appreciated by green and impact investors: green bond issues (over US$300 billion, in 2020) may allow railway companies to fund, with particularly advantageous conditions, infrastructure projects and the renewal of rolling stock.

Unlike previous years, the European railway system can finally count on significant financial resources to support its investments.

Main Strategic Areas for Rail Investments

The railway sector is implementing important initiatives to continue improving its own sustainability (see, for example, the framework of initiatives outlined by UIC in the document "Technical Solutions for the operational railway", published in 2020; the overall picture outlined by the International Energy Agency in the report "The future of rail", published in 2019; and the remarks contained in the chapter on transport of the Intergovernmental Panel on Climate Change Assessment – IPCC Report).

The fundamental objective is to increase the energy efficiency for rolling stock, operations and infrastructure, including by enhancing rolling stock and engine performance, using lightweight materials, increasing freight load factors and passenger occupancy rates.

Reducing the carbon intensity of fuels is another key objective. The electrification of railway networks is a crucial lever, allowing trains to benefit from the share of renewables in energy production. In this regard, it should be noted that, compared to an average of 54% of electrification of lines in Europe, there are countries where the figure is less than 15% (in particular, the Baltic countries), and countries where the percentage exceeds 70% (for example, Belgium, Sweden, Austria, Italy and the Netherlands).

Where electrification is not possible for technical or economic reasons, the oil-based products currently in use need to be replaced with natural gas, bio-methane, biofuels, or hydrogen produced from low (blue hydrogen) or possibly zero (green hydrogen) GHG sources. In 2020, the first hydrogen fuel cell train completed successfully its test operations, proving that hydrogen propulsion is a viable and reliable alternative to diesel-powered regional trains on non-electrified lines.

It must be clear, though, that energy efficiency improvements and emission reductions of trains will be irrelevant without a substantial increase of the modal share of rail transport; shifting passengers and goods to railways is the key strategic objective for Europe.

In the current plans of the European Union and of its member countries, the primary focus is not the construction of new lines. The data gathered by UIC, the organisation that brings together 194 railway companies from all continents, show that only 7% of the lines currently under construction in the world and 15% of the planned new lines (in the authorisation, designing or tendering phases) are located in Europe. Asia clearly leads the way (hosting 72% of lines under construction and 42% of new lines planned), and Africa and the Americas host more ongoing projects than the Old Continent (despite the substantial absence of investments planned in North America). Likewise, the conditions for the construction of new infrastructures, such as Hyperloop systems, are still unmet in Europe, despite technological advances and pilot projects being monitored.

The main general strategic objectives for rail investments in Europe in the next years can be summarised as follows:

- to finally complete the nine core corridors of the Trans-European Transport Network (TEN-T);
- to rebalance, especially through technological enhancements and other targeted investments, the quantity and quality of links, paying particular attention to the less connected territories;
- to manage the high degree of use of some sections of the network (especially near the main urban centres and on some specific routes);
- to improve the infrastructures for public transport in urban areas;
- to promote the integration between the different mobility systems;
- to increase the attractiveness and reliability of rail transport.

The consequences of climate change (in particular, the increased recurrence of extreme, sudden and destructive climatic events) require substantial investments for the supervision of existing infrastructures, including through the application (where possible) of advanced detection and predictive maintenance systems.

In freight transport, the reliability, peed and economic convenience of rail transport would be improved by an extensive investment plan on:

- the railway connections between major logistic nodes (ports, airports, freight villages, etc.);
- the elimination of bottlenecks (axle load, length, height, speed, electrification, control command system, etc.);
- the age-old question of interoperability among various countries within the European Union;
- the provision of alternative routing solutions in cases of temporary interruption of some fundamental lines. Operators remember well the consequences of the

> Rastatt accident in Germany in 2017, in which the closure of a railway section for 7 weeks generated a financial damage estimated at over €2 billion and heavy and long-term repercussions on the confidence of potential customers.

While policy makers must keep their promises and provide a complete redesign, in a sustainability perspective, of the incentives and disincentives system for transportation, rail freight companies need to evolve their approach to customer needs (reliability, speed, traceability and flexibility, above all), becoming capable, through investments and digital transformation, of offering multimodal door-to-door transport solutions, thus achieving a strategic repositioning which would allow them to get control over the most profitable links in the value chain.

In rail passenger transport, alongside the quality of rolling stocks, for which substantial renewal plans are already underway in many countries, investments in the coming years will be aimed at favouring intermodality, which is the only possible way by which rail services can aspire to equal the comfort and flexibility of private cars. This is far from a simple objective: it requires collaboration and integration between operators from different fields and the support of specific digital platforms that identify the best combinations of different means of transport, including individual door-to-door preferences and real time adaptability to changes intervening during the trip. In this regard, major projects have existed for several years, but no operator has managed to offer attractive services to gain visibility and increase volume yet.

Digital-based intermodality is the fundamental strategic challenge for railway companies: if they fail to create usable and successful platforms through which they can assert their role as the backbone of the mobility system, they will end up being disintermediated and dominated by platforms created by others. The sector awaits the definition of a European data strategy capable of supporting the natural digital transformation without producing dangerous phenomena of digital disintermediation by private platforms, mainly outside Europe, which could benefit from a very strong position in the possession and management of data. For mobility companies, in the near future, there is a strong risk of suffering what Amazon has done to the retail sector or what Airbnb, Expedia and Booking have done to tourist accommodation in the hospitality sector.

Therefore, to promote intermodality, significant interventions are planned concerning rail stations, which should become welcoming, attractive, safe and efficient mobility hubs for future mobility. Enhanced train stations will facilitate intermodal and seamless travel solutions by embracing the traditional means of transport (such as private and shared cars, which will increasingly become zero-emission), and more innovative ones, which do not yet exist, at least not everywhere. The main investments on stations concern the integrated design of infrastructure and connection services, the optimisation of road, cycle and pedestrian accesses, the requalification of the surrounding urban environment, the improvement of safety, as well as the smart integration of the timetables of rail services and of other means of local public transport.

Three Underestimated Enabling Factors

A solid long-term vision for the transport system

Transportation infrastructure investments require huge amounts of capital and have long or very long lead times. It is therefore necessary – at the European, national and regional levels – to define and agree upon a broad and long-term vision for the mobility system, one that ensures the necessary cohesion of the Union while embracing the diversity of territories and local communities, from both an intra-European and a global perspective.

Having a long-term vision – based as much as possible on solid methodological foundations, shared on a political level and stable over time – would offer support even to the most difficult changes and would take away pressure from the interest groups that defend the status quo. For example, a long-term vision would help develop more awareness of existing problems (such as congestion in urban centres, road safety and the consumption of natural resources) that cannot be overcome simply because engines will become zero-emission.

Such a vision should include the main factors of change that will affect mobility in the coming decades, such as:

- Demographic and social factors: population ageing (people aged 65 and over currently account for 20% of the EU-27 population and will rise to almost 25% in 2030), further urbanisation trends (currently, 75% of EU citizens lives in an urban area) accompanied by the risk of greater exclusion of decentralised and lower density areas and changes in the consumption habits of the new generations;
- Environmental factors: the need for decarbonisation and reduction of the most harmful pollutants (such as fine particulate matter, which in some areas of Europe, especially in Poland and northern Italy, reduces life expectancy by more than one year, as shown by the Air Quality Life Index produced by the Energy Policy Institute at the University of Chicago), as well as the need for adaptation to the greater frequency of extreme climatic events;
- Economic and technological factors, concerning the electrification of road mobility and the application of digital technologies.

A mature, conscious and active approach to innovation

The opportunities offered by technological innovation, in particular digital, are a further factor that will influence rail investments in the coming years.

Digital technologies have dramatically changed all industries, all value chains, all production and consumption processes. The traditional distinction between tangible and intangible infrastructures is largely overcome and the ability to seize the opportunities that arise from the convergence between physical and digital technologies is an extraordinary lever for improving the impact of public investments. Currently, for example, sensors are already widely used for the safety of infrastructures, of the workers building and maintaining them, as well as of the people using them. Signalling and communication technologies improve safety, efficiency and capacity of transport networks. Furthermore, rail industry stakeholders continue to assess and employ emerging technologies, such as unmanned aerial and terrestrial drones, AI assisted and automated trains, predictive analytics, rolling data centres, machine vision, instrumented rail inspection systems, etc .

The pace of innovation, however, is difficult to reconcile with investments that require economies of scale, lengthy amounts of time for design, construction and economic return, and the consumption, often irreversible, of soil and other natural resources.

Therefore, the system that governs infrastructure investments, in all its components, needs a mature, conscious and active approach to innovation.

Enthusiasm and openness to innovations are a fundamental prerequisite, but it is necessary to manage the risks of the so-called hype-cycle phenomenon, concerning the spread of disproportionate expectations on the value and potential of technological innovations, especially digital, and on the time actually necessary for them to be metabolised and implemented by the companies. The announcement and introduction of technological innovations are always followed by an initial sensationalist phase, resulting in inflated expectations, far from the principles of economic rationality. Without "deep" thinking and the ability to understand the implications and limits of technologies, there is a huge risk of being dragged along by a novelty effect, wasting precious resources. Only after a phase of disappointment, in which underestimates are very common, does the actual value potential of technologies emerge.

New technologies, particularly digital ones, are the fundamental tools to face the most current challenges for the railway sector, as briefly summarised in the second paragraph. The improvement of mobility in Europe – both from the point of view of environmental sustainability and productivity of the entire European system – depends on the ability of the railway sector to assess and choose the best technologies and to implement them quickly.

On all the fundamental issues, we could achieve many improvements simply by implementing available digital technologies. For example, the implementation of ERTMS (European Rail Traffic Management System) signalling and communication systems and 5G networks requires everyone's commitment: we need to accelerate investments and rapidly proceed to share the regulatory framework at European level and within the various countries. Some valid projects have laid the foundations for fundamental cross-country cooperation (for example, Shift to Rail and its successor, the Europe's Rail partnership).

Finally, for an area of the world that aspires to maintain its leadership on the international scene, it is necessary to promote an active attitude towards innovation, which is not confined to the usage of widely tested and universally adopted technologies. We need to find a balance point that allows us to constantly monitor new opportunities and promptly adopt valid technologies, while avoiding wasting resources, investing in technologies without real consistency and prospects. For a community that in many sectors manages to make creativity its strong point, it is important to set the goal of actively participating in the shift of the technological frontier, while taking on the role of exporter of technologies and innovation.

Neutral and highly specialised associative realities, such as Union International des Chemins de Fer, may play an important role, by embodying and conveying a system-wide vision, defining up-to-date technical standards and technical positions, producing specifications / guidelines and technical policies, leveraging data and sharing of experience, favouring joint innovative projects and accelerating the innovation cycle.

The quality of the investment governance system

In providing some remarks on the future of investments in the railway sector, a few words on the institutional framework – which governs the planning, executive and control processes of public investments, at the European, national and regional levels – are inevitable.

The European framework is particularly diversified, but in all countries there is ample room for improvement in terms of timing and stability of investment decisions, of clarity in the separation of political, technical and economic assessments, of clarity in the attribution of competences and, more generally, of accountability.

For some countries, these are real shortcomings, which require urgent reforms. In Italy, for example, as reported in a study on recent large-scale infrastructural projects (NUVEC-ACT Report), the total time required for the construction of an infrastructure worth more than €100 million, from preliminary design to inauguration, is approximately 15 years. The phases that precede construction (design, authorisation and negotiation) require approximately the same time as the actual building phase (7-8 years), and are subject to administrative procedures that involve several institutions, sometimes delayed by unjustified iterations. The most recent interventions by the Italian Government and Legislator have moved in the right direction and the Reform section of the Italian National Recovery and Resilience Plan specifies further interventions and timings.

It is highly probable that no Western country could replicate the extraordinary results of the People's Republic of China, which in the last 20 years has put into operation 36,000 km of new high-speed railway lines (in Europe, only 8 countries have high-speed lines and the entire network spans 12,000 km) and is planning a further 5,000 km for the next 10 years (equal to those planned, overall, in Europe). As a result, the Chinese share of global high-speed rail transport volumes (source UIC) was 75% in 2019 (with a 57% increase since 2010, when it was 18%).

While respecting the founding values of the European Union and guaranteeing the requirements of legality and accountability, the simplification of the authorisation and decision-making processes cannot be further delayed, as it is a fundamental enabler for accelerating infrastructure investments and the transition towards a sustainable mobility model.

Concluding Remarks

Rail transport, with its absolute primacy in terms of environmental sustainability, represents the key lever for reducing transport emissions. Europe has both the responsibility and the technical and financial capabilities to act as a trailblazer in proposing new models of sustainable mobility.

Over the next few years, the rail sector will eventually benefit from unprecedented political and financial support, which should make it possible to win the decarbonisation challenge and achieve a significant modal shift of passengers and goods to rail.

All operators, though, are aware that no substantial change will be possible without the contribution of at least three fundamental enablers: i) a solid, agreed-upon and sustainable vision for the future of the transport system, ii) a mature approach to innovation and iii) high-quality governance processes for infrastructural investments.

6.5 The Contribution of Maritime Transport and Short-Sea Shipping to Sustainability

Kurt Bodewig

The maritime sector is the most critical transport sector. Roughly 80% of all goods are transported by sea, and in terms of tons per kilometre travelled, shipping is the most efficient and cost-effective transport mode.[1] The Trans-European Transport Network (TEN-T) is a large network consisting of 335 ports. EU-owned ships represent 41% of the global merchant fleet and trade on all oceans, serving markets all over the world.[2]

Furthermore, the European maritime sector is also considered central to ensure efficient trade in and out of the European Union, as well as connecting the mainland to Europe's peripheral regions and islands. In this context, it is worth reflecting on how the ongoing pandemic is affecting the economy and the maritime sector specifically, and where the potential to achieve an economic recovery after the pandemic may lie.

Global trade has contracted more now than during the financial crisis in 2008-09. At the same time, the maritime transport sector forms a large part of the intra-European transport system, facilitating and redistributing trade flows from land-based route networks, while contributing to the efforts to reduce the overall external environmental and social costs from transport.

Short-sea shipping accounts for around 65% of all cargo transiting through EU ports, or 2.5 billion tons of cargo and more than 400 million passengers embarking or disembarking from European ports each year.[3] While the longer-term impact of the Covid-19 outbreak is yet to be fully understood, the

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[1] United Nations Conference on Trade and Development (UNCTAD).

[2] Ibid.

[3] Eurostat.

immediate challenges differ depending on the region and the maritime transport segment, for instance container transport, bulk transport or tankers. It also depends on whether the transport operation is domestic or international.

The number of ship calls in Europe increased by 1% in February 2021 compared to the same month in 2019. The most significantly affected sectors have been cruise ships, passenger ships, refrigerated cargo ships and vehicle carriers. Meanwhile, the number of Ro-Ro passenger vessels had an increase of 11%.[4] Consequently, one of the points to be highlighted has been to boost short-sea shipping in the EU. There is already a notable and steady growth in the use of short-sea shipping routes. Quicker expansion and reinforcement of short-sea shipping could strongly contribute to the competitiveness and sustainability of the EU transport and logistics chain. Thus, short-sea shipping is an essential link in the European logistic chains. It also enhances the resilience of the transport sector by increasing the number of more sustainable transport and logistic solutions. More attention towards short-sea shipping is needed. At the same time it is important to reinforce the modal shift from road transport to short-sea shipping. It is also a crucial topic and highly relevant in view of the upcoming TEN-T Regulation revision.

In addition to short-sea shipping, the ongoing pandemic has shown us that resilience can be multifaceted. Resilience against climate change is not the only kind of resilience we need to develop. The modal shift from road to maritime transport must increase and it could be one of the driving factors to make short-sea shipping, for instance, a more attractive mode of transport. Cost-effectiveness, lower carbon emissions and reduced road congestion are just a few examples of the advantages of short-sea shipping.

However, as mentioned earlier, there is also a need to develop resilience against disruptive changes to our logistic chains and industrial production, as we have learned following the outbreak

[4] European Maritime Safety Agency: COVID-19 – impact on shipping (March 2021).

of the virus last year. In the recently held Motorways of the Seas Forum, one of many good points raised was the need to better recognise the cross-border character of ports and to underline the fact that ports bring trade to and from the whole world. Ports are also energy hubs, and they will become even more important as points for the production, supply and import of renewable energy in the future. This can also contribute to greater sustainability of the whole transport sector. Another example is the establishment of a Sulphur Emission Control Area (SECA) in the Mediterranean, which is a step in the right direction to improve the sustainability of the sector, and to make short-sea shipping a more attractive transport mode.

Similar measures have been implemented in other sea basins, such as in the Baltic Sea. Stricter sulphur limits have more than halved sulphur dioxide concentrations, bringing health benefits to people in coastal regions and ports, while the overall economic impacts on the sector have remained minimal.[5] Therefore, we can assume that similar sulphur emission control areas in the Mediterranean could be feasible measures to improve sustainability.

The crisis has challenged global and European supply chains. This has given rise to calls for more autonomy in our production. There are many lessons to learn from the ongoing crisis, and businesses are already revising their risk management strategies. European trade policy can help by making it easier to diversify sources of supply in order to become more autonomous. For instance, the EU's new "Open Strategic Autonomy", a compass for EU trade policy at a time of economic transformation and geopolitical instability, is moving in this direction.

Global trade and its integrated value chains will remain a fundamental growth engine and will be essential for Europe's recovery. The recovery is likely to be long, but the needs are immediate. Several financial instruments will be used for

[5] European Commission, "Cleaner Air in 2020: 0.5% sulphur cap for ships enters into force worldwide", 3 January 2020.

Europe's recovery. The Next Generation EU fund is just one example, which includes the instruments of the Recovery and Resilience Facility, Horizon Europe and InvestEU. In this context one must also mention the Green Deal and the Connecting Europe Facility.

The Recovery and Resilience Facility offers an opportunity for more guided support to ports and the maritime sector. The maritime sector can be a part of the solution within the above-mentioned instruments. Investments in ports to develop them into industry clusters or energy hubs will not only increase the sustainability but also boost the resilience of supply chains. This, then, can also have positive effects on short-sea shipping.

Resilience and competitiveness go hand in hand. To maintain our European resilience, we must also reflect on how European manufacturers can remain competitive in view of increasing competition from Asia. We will have to address this as well in the recovery of European economy that lies ahead of us. This includes the digitalisation of the transport sector as a whole, and in the maritime sector specifically.

In the forthcoming next version of the Report "Shaping the future policy of the European Maritime Space" (Motorways of the Sea Detailed Implementation Plan of the European Coordinator)[6] it will be important to also include resilience. More specifically, it should address the following needs:

- To encourage more maritime connections in order to enhance resilience. As mentioned previously, short-sea shipping plays a key role in ensuring continued transport flows of goods and people during the pandemic. Developing stronger short-sea connections between European Member States and the core network corridors is essential. More connections will offer more alternatives if specific segments of the TEN-T were to be affected in the future.

[6] European Commission, *Shaping the future policy of the European Maritime Space. Motorways of the Sea, Detailed Implementation Plan of the European Coordinator*, June 2020.

- To digitalise the maritime sector. As mentioned earlier, the pandemic has shown us the benefits of meeting urgent needs while minimising human interaction.
- To equip ports with the appropriate infrastructure to ensure that they can maintain operations of critical services during future crises. This is very important. Infrastructure dedicated to climate change adaptation such as breakwaters or dykes is also key in this respect.
- The European transport system depends on the use of fossil fuels. It is fundamental to diversify our energy usage, by fostering the use of alternative fuels onboard vessels and in ports. Reducing greenhouse gas emissions from the maritime sector will also reduce its impact on the environment.

To conclude, there is no doubt that maritime ports are key for our international connectivity, for the European economy, and for the European regions. European ports are vital gateways as they link Europe with the rest of the world. The development of ports is essential to contribute to the objectives of the European Green Deal and of the Sustainable and Smart Mobility Strategy.

However, the attractiveness of maritime transport chains depends on the efficient integration of maritime and hinterland transport. The Motorways of the Sea are therefore very well placed to support the European shipping industry and ports. To ensure multimodality can occur seamlessly we need to overcome the current rigidities, complexities and fragmentation of the processes, procedures and information flow related to the ports' operations for cargo.

Ports have great potential to become new clean energy hubs for integrated electricity systems, hydrogen and other low-carbon fuels, as well as testbeds for waste reuse and the circular economy. There are several major and important tasks in front of us. It is crucial to strengthen the positive developments of the European maritime sector, and to find ways to create better interconnectivity between the European sea basins on one hand, and the sea basins with the rest of the TEN-T on the other.

6.6 The Role of Sustainable Aviation Fuels in Decarbonising Air Transport

Alexandra Covrig, Inmaculada Gómez Jiménez

The "greatest challenge and opportunity of our times" – this is how European Commission President, Ursula von der Leyen, described the European Union's ambition to become the first climate-neutral continent. It is indeed a twofold ambition: a chance to build better and shape a climate-resilient society, and an ultimatum to act on climate change. The 2019 Emissions Gap Report,[1] issued by the United Nations Environment Programme (UNEP), stresses that global emissions need to be cut by 7.6% every year until 2030 to keep the increase in global temperature below 1.5 degrees Centigrade. Efforts must be ramped up to ensure such a dramatic reduction in emissions, and the EU is one of the frontrunners in this direction. The European Green Deal[2] paves the way towards achieving climate neutrality by 2050, and is complemented by the 2030 Climate Target Plan,[3] which aims to cut emissions by at least 55% by 2030.

The world is facing a climate emergency and though progress is indeed being made, the question is whether it can be made fast enough. The fifth assessment report by the Intergovernmental Panel on Climate Change (IPCC)[4] made it clear that human activity is the dominant cause of global warming, given economic and population growth. Accelerated large-scale efforts at a global level and in all sectors are required to ensure that the 1.5 degrees Centigrade limit is respected, curbing global warming and reducing greenhouse gas emissions. Based on statistics from

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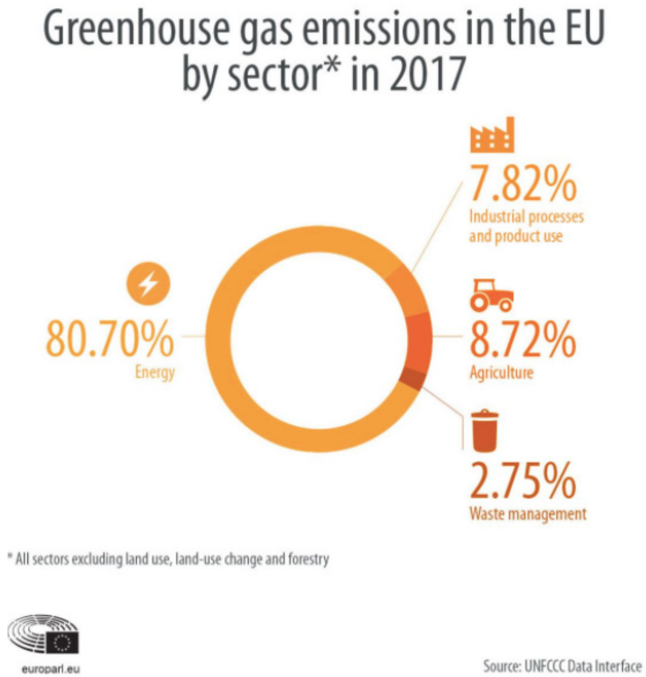
[1] *Emissions Gap Report 2019*, UN Environment Programme, 26 November 2019.

[2] European Commission, A European Green Deal.

[3] European Commission, Climate Action, 2030 Climate Target Plan.

[4] *AR5 Synthesis Report: Climate Change 2014*, Intergovernmental Panel on Climate Change (IPCC), Geneva, 2015.

the EU, retrieved in 2017, energy is responsible for 80.7% of greenhouse gas emissions, with transport accounting for a third of this figure. Agriculture accounts for 8.72%, industry for 7.82% and waste management for 2.75%.



Greenhouse gases emissions by sector in the EU in 2017

According to the *European Aviation Environmental Report* (2019), the aviation sector accounts for approximately 3% of global CO_2 emissions and 4% in Europe. To achieve the EU's 2050 carbon neutrality goal, aviation stakeholders, including industry and policymakers, must be part of the solution and actively participate in developing sustainability measures to reduce carbon emissions. Economic growth and climate action go hand in hand, and collective policies and actions can set the seal on a net zero carbon future. A study by the Royal Netherlands Aerospace Centre and SEO Amsterdam

Economics, *Destination 2050: A Route to Net Zero European Aviation* (2021),[5] assessed different sustainability measures, their impact and the role of policies and actions in the carbon emissions reduction process, and proposed recommendations to industry and government for sustainable aviation. These are presented in the following list:

Industry should

- Continue to substantially invest in decarbonisation
- Develop more fuel-efficient aircraft and bring these into operation through continued fleet renewal
- Develop hydrogen-powered and (hybrid-)electric aircraft and associated supporting (airport) infrastructure and bring these into the market
- Scale up drop-in SAF production and uptake
- Implement the latest innovations in ATM and flight planning
- Compensate remaining CO_2 emissions by removing carbon dioxide from the atmosphere

Governments should

- Support industry investments by direct stimuli or by reducing investment risk through a consistent and long-term policy framework
- Stimulate further development and deployment of innovations by funding research programmes and promoting carbon removal technologies
- Work with the energy sector to ensure sufficient availability of renewable energy at affordable cost
- Support the development of the SAF industry
- Contribute to optimising ATM, in particular by fully implementing the Single European Sky

To decarbonise air transport, collaborative action and innovation are key. On the one hand, it is crucial that all stakeholders get involved, not just aviation experts, policymakers and researchers, but also players from the finance sector and the energy industry. As we have seen during the Covid-19 pandemic, engagement and collaboration across sectors permit a holistic response to such a disruptive event. While the pandemic caused a near total shutdown of air transport at a global level, it also altered our vision of long-term growth, given its impact on the economy and the slow recovery of air traffic. Industry and governments must work together to invest in the environment and in better aviation. A long-term strategy for emissions reduction which focuses on financing research for new technologies, energy transition and fuel efficiency must be put in place collectively. In particular, innovation in air transport can provide the tools for decarbonising aviation. Technology, energy systems and operational measures such as sustainable fuels, electric and hybrid flights, and zero carbon connectivity can support achievement

[5] *Destination 2050: A Route to Net Zero European Aviation*, February 2021.

of the 2050 climate neutrality goal. Innovation, backed by policy and investment, together with collaboration between all stakeholders, has the potential to drive decarbonisation. In the aftermath of the Covid-19 pandemic, aviation has an opportunity to start afresh by scaling up alternative sustainable fuels, shifting to clean energy and taking up new technologies such as electric, hybrid and hydrogen aircraft.

Since the first commercial flight in 1914, air transport has continued to provide connectivity to the world while slowly progressing towards sustainability. Ever since that first flight, operational efficiency has been enhanced with the aid of new technologies. The CO_2 emissions produced by a passenger flight today are 54.3% less than those the same flight would have produced in 1990, according to IATA Economics data. Fuel efficiency has always played an important role in air transport sustainability and continues to do so, but possible improvements are only marginal and are destined to decrease. The first certification standard for the use of synthesized kerosene in commercial flights was issued in 2009 for the Fischer-Tropsch production system. On 1 July 2011, the standard for producing sustainable aviation fuel (SAF) from vegetable oils and fats (HEFA) was issued. Up to 8 processes are already available to produce SAF using different technologies, and a significant number of additional processes are progressing towards certification. During the first years, SAF was supplied only for certain flights at specific blend ratios. In 2015, the first commingled supply at Oslo International Airport, developed by the European project ITAKA, proved a gamechanger, allowing for regular operations to be made on SAF blends on a continuous basis. Nowadays, several airports are regularly supplying SAF and today, based on data from IATA, over 300,000 flights take to the skies fuelled by SAF, with approximately 7 billion litres of SAF purchased and over 45 airlines operating with SAF.

Theme	Principle	Criteria
Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis
Carbon Stock	Principle: CORSIA eligible fuel should not be made from biomass obtained from land with high carbon stock	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/ or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all havehigh carbon stocks
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (LUC) value, the DLUC value shall replace the default ILUC value

The road to net zero CO_2 emissions includes various measures such as advancements in aircraft and engine technology, fleet replacement, air traffic management efficiency, the decarbonisation of ground operations, the deployment of sustainable aviation fuels, market-based cost-efficient economic measures, and intermodal transport. This chapter focuses on sustainable aviation fuel.

Why should we use sustainable aviation fuel and what is its role in achieving net zero carbon emissions by 2050? Produced from sustainable waste feedstocks such as cooking oil, animal waste fat, solid waste (packaging, textiles, paper, food scraps, forestry waste), and sustainable energy crops (e.g. algae), sustainable aviation fuel is in line with environmental, economic and social targets. For a fuel to be classified as "sustainable", it must meet certain criteria, depending on the regulatory framework in place where the SAF is to be used. In the context of international aviation, sustainability criteria as defined by ICAO and consist of two principles, greenhouse gases and carbon stock, though other sustainability principles and criteria are being discussed by ICAO's Committee on Aviation Environmental Protection (CAEP). Currently agreed criteria are illustrated in the table below, taken from Environmental Protection, Volume IV – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). SAF complying with these principles and criteria counts towards CO_2 reductions under CORSIA obligations.

Tab. 1 – Corsia sustainability criteria for corsia eligible fuels

JetSCREEN (Closed project)	The ambition of the JETSCREEN program is to deliver, for candidate fuels, a certificate of analysis where the key results of the ASTM D4054 approval process are listed.
EABF FlightPath (Closed project)	The initiative committed members to support and promote the production, storage and distribution of sustainably produced drop-in biofuels for their use in aviation and establish the appropriate financial mechanisms to support the construction of advanced biofuel production plants in Europe.
RewoFuel (Closed project)	The aim of the project REWOFUEL is to demonstrate the performance, reliability, environmental and socio-economic sustainability of the entire value chain for the transformation of residual wood to bio- Isobutene (bio-IBN) by fermentation and its further conversion into biofuels.
Sun2Liquid (Closed project)	The SUN-to-LIQUID approach uses concentrated solar energy to synthesize liquid hydrocarbon fuels from H_2O and CO_2.
ITAKA (Closed project)	Initiative Towards sustAinable Kerosene for Aviation project focused on cultivating an energy-efficient culture for the next generation to fly higher with the metal wings.

FLIGHTPATH (Closed project)	Flightpath or the European Advanced Biofuels Flightpath initiative aimed to bring sustainable aviation fuels to the market through the promotion of national and regional measures by the different agents involved in the sector.
Bio4A (Ongoing project)	The aim of BIO4A is to enable a large-scale pre-commercial production of aviation biofuel from sustainable (biogenic waste) feedstock in the EU.
FlexJet (Ongoing project)	FlexJet will build a pre-commercial demonstration plant for the production of advanced aviation biofuel (jet fuel) from waste vegetable oil and organic solid waste biomass (food waste)
BIOSFERA (Ongoing project)	BioSFerA aims to develop a cost-effective interdisciplinary technology to produce sustainable aviation and maritime fuels.
FLITE (Ongoing project)	The Fuel via Low Carbon Integrated Technology from Ethanol (FLITE) consortium (LanzaTech, SkyNRG, E4tech, RSB, and Wavestone) proposes to expand the supply of low carbon jet fuel in Europe by designing, building, and demonstrating an innovative ethanol-based Alcohol-to-Jet (ATJ) technology in an ATJ Advanced Production Unit (ATJ-APU).
BL2F (Ongoing project)	Black Liquor to Fuel (BL2F) process produces drop-in biofuels for aviation and shipping from black liquor, a side stream of chemical pulping industry.
TAKE-OFF (Ongoing project)	TAKE-OFF is an industrially driven project that will be a game-changer in the cost-effective production of sustainable aviation fuel (SAF) from CO_2 and hydrogen.
KEROGREEN (Ongoing project)	KEROGREEN offers a novel conversion route to sustainable aviation fuel synthesised from H_2O and CO_2 powered by renewable electricity.
ALIGHT (Ongoing project)	Copenhagen Airport launched an ambitious climate strategy in 2019. The plan is for the airport to become emission-free with emission-free transport to and from its premises by 2030. Assisting in this eco-transformation, the EU-funded ALIGHT project will develop two solutions. The first is the supply, implementation, integration and smart use of sustainable aviation fuel. The second is the development and implementation of a smart energy system.

Since 2009, the European Union has also established sustainability and greenhouse gas reduction criteria for biofuels in its Renewable Energy Directive (currently RED II Directive 2018/2001[6] on the promotion of energy from renewable sources). RED II requires that by 2030 all EU Member States ensure that a minimum of 14% of their transport energy is produced via renewable sources. The decarbonisation of air transport is further supported in Europe by the EU Emissions Trading System (EU ETS),[7] which stimulates aircraft operators to use aviation fuel that complies with RED sustainability criteria. In addition, the European Union is currently discussing the implementation of a new regulation, called ReFuel-EU to impose SAF blend obligations according to the sustainability rules set in the above-mentioned RED directive.

Aviation is a global transport sector and sustainability criteria and incentives should preferably be globally harmonised. In general terms, there is an international agreement concerning sustainability criteria at international, regional and local levels based on the same principles: sustainable aviation fuel should not compete with food and water, should reinforce social and economic development, should minimise impact on biodiversity and should reduce net greenhouse gas emissions on a lifecycle basis. The problem lies in the divergent ways in which these general principles and criteria are applied under different regulatory frameworks.

SAF can make a considerable contribution to reducing greenhouse gas emissions. Compared to traditional jet fuel, SAF can reduce carbon emissions by up to 80% over the lifecycle of the fuel. Unfortunately, only 0.05% of the jet fuel consumed is supplied by SAF at the present time, which obviously limits its effective impact. If supported by long-term policy and provided industrial production capacity improves, the supply

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[6] Official Journal of the European Union, L 328/82, Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

[7] European Commission, EU Emissions Trading System (EU ETS).

of SAF in Europe may increase from 3 Mt in 2030 to 32 Mt in 2050 (Destination 2050, 2021). Given its great potential, the need for SAF development and deployment was highlighted by ICAO in its Resolution A40-18 (2019) and in the 2050 ICAO Vision for Sustainable Aviation Fuels,[8] through which Member States were requested to assess and adopt measures to ensure the sustainability of alternative aviation fuels.

Thanks to its benefits, SAF is on the rise and investment in targeted research and development is reflected in various European-funded projects such as those listed below:

- SAF consumption in Europe is currently still very low. The right policy actions backed by investment in production facilities and industrial development are needed to, accelerate the shift to sustainable aviation fuels and overcome the barrier of higher production costs. A strong policy framework and innovative measures can shape a better outlook for the future.
- SAF is an economically viable option for airlines and airports. Europe is committed to reducing environmental impact, but the path towards achieving the relevant targets is paved with challenges. Each of these can nevertheless be overcome if the entire aviation industry, including its policymakers, comes together to narrow the gap between growth objectives and climate goals.

[8] Resolution A40-18 (2019) and the 2050 ICAO Vision for Sustainable Aviation Fuels, Resolution A40-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection - Climate change.

7. The Role of Digital Infrastructure in Fostering the Sustainable Transition. What's Next for Mobility?

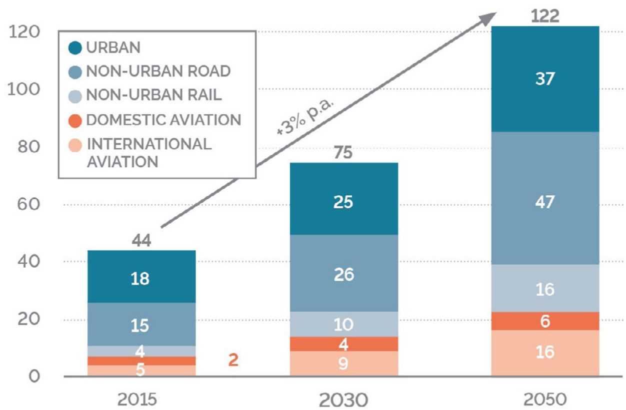
Luca Milani, Stefano Napoletano, Andrea Ricotti, Nicola Sandri

Introduction and Environmental Impact of the Transport Sector

The transport sector currently accounts for 25-30% of European greenhouse gas (GHG) emissions. Moreover, considering GHG emissions by transport sub-sector, road transport alone constitutes the highest proportion of overall emissions, with over 70%. The relative contribution of transport to overall GHG emissions in Europe has become more significant in recent years, as this industry has not followed the general reduction trend observed in other sectors. Moreover, demand for both passenger and freight transport is expected to grow significantly in the years ahead, with a potential further increase in negative externalities on environmental sustainability.

According to the OECD International Transport Forum (ITF) projections shown below, global demand for passenger transport is projected to increase three-fold between 2015 and 2050, from 44 trillion to 122 trillion passenger-kilometres, representing a growth rate of 3% per year. Considering transport by type, urban passenger transport alone is expected to more than double by 2050 (from 18 trillion passenger-kilometres in 2015 to 37 trillion passenger-kilometres in 2050), equating to a growth rate of 2% per year.

Fig 7.1 – Global demand for passenger transport by type (trillion passenger-kilometres)



Source: ITF Transport Outlook 2019

Similar patterns can be observed for freight transport. Indeed, global freight demand is expected to triple by 2050, according to OECD International Transport Forum (ITF) projections: freight demand is expected to increase from ~110 trillion t-km transported worldwide in 2015 to ~170 trillion t-km in 2030 and ~350 trillion t-km in 2050, equating to a growth rate of 3% per year between 2015-2030 and 4% per year between 2030-2050.

The Importance of Digital Infrastructure and Technologies in Fostering the Sustainable Transition in the Transport Sector

Decoupling transport activity from CO_2 emissions will be essential if we are to achieve the climate goals set by global institutions in recent years, while at the same time maintaining the mobility of passengers and freight flows. The Paris Agreement in 2015 constituted a global consensus on the magnitude of the risks deriving from climate change. In addition, the United Nations General Assembly adopted 17 Sustainable Development Goals (SDGs) to be addressed by 2030 as part of the Agenda for Sustainable Development. Some of these goals are specifically linked to sustainable transport, including, for example, reducing deaths and illness from pollution; developing sustainable and resilient infrastructure; providing access to safe, affordable, accessible and sustainable transport systems for all, and reducing the adverse environmental impact of cities. Moving to more sustainable transport means putting users first and providing them with cleaner, healthier and more affordable alternatives. It is therefore vitally important for national stakeholders (e.g. general governments and local municipalities, public and private companies, individuals) to formulate strategies to achieve the above-mentioned goals. It is also clear that digital technologies and infrastructures will constitute crucial enabling factors to foster the sustainable transition, with potential applications to a wide array of transport infrastructures, in both urban and extra-urban areas.

As far as extra-urban areas are concerned, digital technologies designed to enhance the environmental sustainability of transport infrastructure can be implemented in rail, airport, road and port spaces:

- **Rail**: deployment of advanced train-control and signalling systems (e.g. ERTMS level 2 and above and using wireless communications to supervise train movement) is a core element of the digitisation of train control and traffic management. Furthermore, digital improvements will eventually enable the rail sector to meet the European goal of attaining a 30% share of freight transport by 2030, from current levels of ~18%, to neutralise the higher negative impact of trucks, thus leading to higher environmental sustainability.

- **Airports**: multiple large and medium-sized airports are working on digital innovations and implementing new technologies. While some digital applications are implemented mainly to enhance customers' airport experience (e.g. personalised shopping experience, omnichannel experience), others, such as optimised movement sequencing and smart energy solutions (e.g., smart grid, smart metering), are designed mainly to reduce the environmental impact of the infrastructure.
- **Roads**: the installation of charging infrastructure for electric vehicles is one of the most impactful smart solutions on roads and highways to improve the sustainability footprint of these asset classes. This is why boosting and promoting the adoption of clean vehicles and alternative fuels is among the key priorities on stakeholders' agendas. For instance, by 2025, about one million public charging stations will be needed for the 13 million zero- and low-emission vehicles expected on European roads and the European Commission itself is supporting and financing the deployment of charging and fuelling points where gaps persist.
- **Ports**: technology and innovation also have a significant impact on port operations and the digitisation of the entire maritime supply chain. Digital technologies (e.g. smart objects connected to the cloud and IoT, artificial intelligence and advanced analytics tools to optimize freight scheduling) coupled with further adoption of alternative fuels (e.g. liquefied natural gas, biofuels) will eventually help the shipping sector reduce its GHG emissions in line with International Maritime Organization standards.

Fig. 7.2 – Examples of digital technologies applied to transport infrastructures

ASSET CLASS	EXAMPLES
RAIL	• Advanced train-control and signaling systems, as ERTMS level 2 and above and digital signaling solutions • Wireless technology communications to supervise train movement • Digitized inventory and real-time fleet monitoring • Advanced analytics tools for project performance in construction
AIRPORT	• Optimized movement sequencing, and ascend/descend approach to reduce noise/emissions • Predictive maintenance to reduce maintenance costs and downtime • Smart energy innovations, such as solar farm, smart grid, smart metering, and e-mobility of transportation
ROAD	• "Green Islands" hubs using different renewables sources to produce energy for electric vehicles • Wi-Fi Vehicle to Infrastructure network to support communication between infrastructures and vehicles, based on On Board Units (OBU) and Road Side Units (RSU) • Smart cameras to monitor road network, focusing on critical events, traffic, and status • IoT-based monitoring of road infrastructures
PORT	• Connected objects through IoT and cloud technologies • Autonomous ships, automated guided vehicle, automatic stacking cranes • Data as a Service business model aggregating, structuring, cleaning data for use by the port community • Artificial intelligence and advanced analytics tools to optimize decision making processes (e.g. dynamic scheduling)

Reducing the environmental impact of the transport sector is also a key priority in urban areas, where transport is currently the main cause of air pollution. Digital technologies and infrastructures will act as fundamental enabling factors to reduce GHG emissions and fuel consumption in this context too, thus helping meet new environmental standards, boost public satisfaction and create an urban smart mobility ecosystem in the long-term. Indeed, multiple smart applications and digital technologies have become more and more relevant to both the present and future of cities. The most interesting examples of these solutions can be clustered into new modes of mobility and upgrades to existing infrastructure and services:

- **New modes of mobility:**
  - — Shared-mobility: access to short-term car, motorcycle and bicycle use without full ownership. These services can typically be round-trip (station-based) or one-way (free-floating).
  - — Micro-mobility: access to short-term e-mopeds without full ownership.
  - — Demand-based micro-transit: ride-sharing services with fixed routes, fixed stops or both, often supplementing existing public transit routes. Algorithms use historical demand to determine routes, vehicle size and trip frequency. These solutions may include options to reserve seats.
  - — E-hailing (private and pooled): real-time ordering of point-to-point transport from a mobile device. Pooled e-hailing involves dynamically matching separately called rides with compatible routes to increase vehicle utilisation.
- **Upgrades to existing infrastructure and services:**
  - — Intelligent traffic signals: improvement of overall traffic flow by dynamic optimisation of traffic lights and speed limits, leading to higher average speeds on roads and less frequent stop-and-go conditions. These applications include traffic light pre-emption technology, which gives priority to emergency vehicles, public buses or both.
  - — Congestion charges: fees for private car usage in certain urban areas at times of peak demand.
  - — Integrated multimodal information: real-time information about price, time and availability of transport options across multiple modes.
  - — Smart parking: systems that guide drivers directly to available spaces. These systems can also influence demand by means of variable fees.
  - — Digital public transit payment: digital and contactless payment systems in public transport that allow

for prepayment and faster boarding. Includes smart cards and mobile payments.

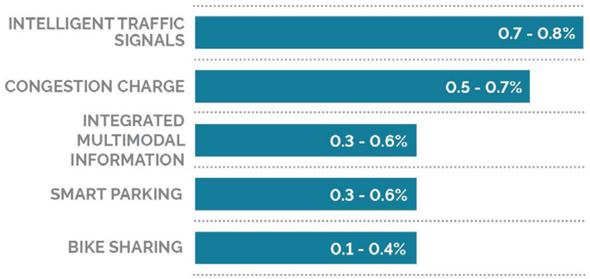
- Predictive maintenance of transport infrastructure: sensor-based monitoring of the condition of public transit and related infrastructure (such as railways, roads and bridges) so that predictive maintenance can be performed before any potential occurrence of faults and disruptions.
- Real-time public transit information: real-time information about arrival and departure times for public transport modes, including informal bus systems.
- Real-time road navigation: real-time navigation tools to optimise motorists' choice of driving routes, with alerts for roadworks, diversions, congestion and accidents. Largely applies to people driving alone or in a car pool.

The majority of the above mobility applications are primarily designed to reduce commuting times. Indeed, by 2025, cities deploying a full range of intelligent mobility applications have the potential to cut average commuting times by 15-20%, which equates to freeing up an extra 15-30 minutes of commuter's time every workday.

Environmental Benefits, Enablers of Specific Mobility Applications in Urban Areas and Case Studies

Besides having clear benefits on commuting times, the mobility applications outlined above also make a significant contribution to decreasing GHG emissions, thus ultimately improving quality of life in urban areas. The table below, based on a McKinsey Global Institute (MGI) report of 2018, shows details of the potential percentage decrease in GHG emissions yielded by intelligent traffic signals, congestion pricing, integrated multimodal information, smart parking and bike sharing.

Fig. 7.3 – Impact of digital applications on GHG emissions (% decrease in GHG emissions by application)



Source: Report Smart cities digital solutions for a more livable future (McKinsey 2018)

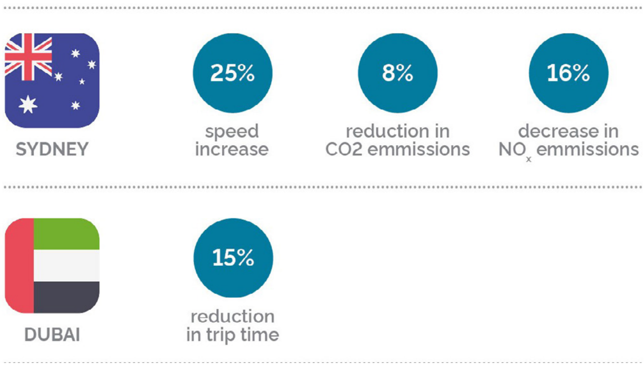
Additional details of empirical environmental benefits, case studies of cities and enablers for proper implementation are set out below.

Intelligent traffic systems improve traffic flows, thereby impacting on commuting time, safety, health and environmental quality. Multiple cities have implemented intelligent traffic systems globally, including Sydney and Dubai:

- **Sydney:** Sydney developed an intelligent traffic system as early as the 1970s. Based on an automatic plan selection from a library that responds to the data derived from loop detectors or road traffic sensors, it uses sensors at each traffic signal to detect vehicle presence in each lane and pedestrians waiting to cross. It is estimated to help increase speed by 25%, decrease CO_2 emissions by 8% and NOX by 16%.
- **Dubai:** the Dubai intelligent traffic system leverages sensors and cameras controlled by a state of the art traffic control centre. Started in 2012 and completed in 2013, the system comprises software and sensors installed at traffic junctions to optimise traffic lights and reduce journey times. The new system adapts traffic

light duration to suit traffic volume, interlinks a number of traffic signals to ensure uninterrupted traffic flow and ultimately achieves a 15% reduction in journey times.

Fig. 7.4 – Benefits of implementation of intelligent traffic signals



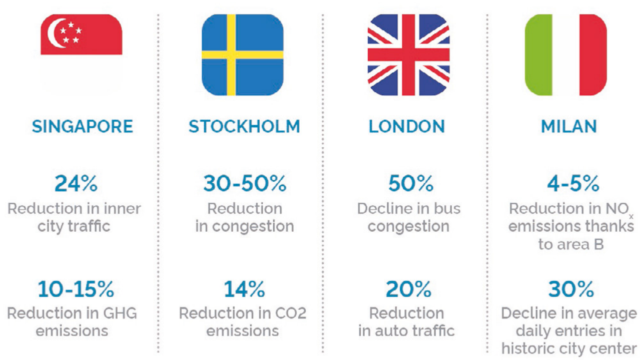
Source: Report Smart cities digital solutions for a more livable future (McKinsey 2018)

Congestion charge mechanisms can be implemented as a cordon fee (e.g. a charge to pass a cordon line around a city centre) or applied to specific urban areas. A digital technology infrastructure has to be installed for proper implementation of these systems, namely electronic transponder devices for vehicles (e.g. E-Zpass or cameras, when not all cars have transponders). The successful implementation of congestion charging in Singapore, Stockholm, London and Milan appears to have had significant impacts mainly on reducing GHG emissions and cutting commuting time:

- **Singapore:** the mechanism deployed in Singapore in 1998 (upgraded from a 1975 scheme) led to a 24% reduction in inner-city traffic, an increase in average speeds from 20 to 26 mph, a 15% increase in bus and train ridership and a 10-15% reduction in GHG emissions.

- **Stockholm:** evidence from Stockholm in 2007 proved that successful implementation of congestion charging led to a 30-50% reduction in congestion, a 4-5% increase in transit ridership and a 14% reduction in CO_2 emissions.
- **London:** the congestion charging scheme introduced in the early 2000s led to a 30% reduction in peak period congestion, a 50% reduction in bus congestion, a 20% reduction in motor vehicle traffic and increases in bus and underground ridership of 14% and 1% respectively.
- **Milan:** the Italian city implemented two different mechanisms of low emission zone and traffic congestion tax, Area B and Area C respectively, applied to specific urban areas: Area B denies access to the most polluting vehicles, whereas Area C charges a fee for access to the historic city centre. As in the other cases, these 2 measures are aimed at reducing environmental impact: for instance, Area C helped reduce average daily entries to the city centre by ~30% in its first year of deployment.

Fig. 7.5 – Benefits of implementation of congestion charges mechanisms



Source: McKinsey analysis

A number of mobility applications have been widely implemented around the globe, but others are still in limited use or in the early development stage. The latter include integrated multimodal information platforms, also known as Mobility-as-a-Service (MaaS). Essentially, MaaS is a new mobility offering combining all modes of transport in a single application and aims to integrate all of the planning, pricing, booking, payment and customer service processes involved in making a journey. In particular, MaaS simplifies access to new forms of shared mobility (e.g. car-sharing, bike-sharing and micro-mobility) by increasing the transparency and convenience of all solutions. These digital systems are expected to bring benefits for users and municipalities. On the one hand, users benefit from improved transparency over itineraries and costs, with all providers' offerings available in a single place and a single transaction. On the other hand, MaaS enables municipalities to benefit from increasingly self-organising and self-optimising transport systems, while giving rise to a better understanding of people's mobility preferences and decision-making processes. Indeed, MaaS helps municipalities manage traffic flows by providing full access to real-time information about travel duration, affordability and eco-friendliness. Furthermore, the data that MaaS generates can lead to invaluable insights for municipalities in terms of travel routes, mobility preferences and decision-making processes. These insights are expected to help municipalities in the short-term, by optimising traffic flows, and in the long-term, by improving the overall transport system and infrastructure, for example, by setting up or incentivising environmentally-friendly alternatives – pilot schemes in North European cities suggest that MaaS might lead to a 50% reduction in private car usage, with consequent positive impacts on environmental sustainability. However, more advanced platforms (i.e. digital platforms, such as Whim, that provide the full spectrum of services, from travel information to pricing/subscription fees), still have a small customer base and are yielding negative margins. In order to solve the issue, MaaS could be integrated with ancillary services to increase uptake and further develop these systems, including solutions for smart parking and payment of ancillary services (e.g. enabling customers to pay congestion charges). Finally, in order to be fully implemented at scale, MaaS/smart mobility platforms require collaboration between diverse stakeholders to offer win-win solutions for all the operators involved: customers, municipal and regional institutions, and transport operators.

Fig. 7.6 – With MaaS, the customer journey is often more complex and less linear than the traditional customer journey

Source: McKinsey

Smart parking is a sensor-based system that detects vacant parking spaces and makes them visible to motorists via mobile applications or vehicle navigation systems. By reducing time spent looking for parking, smart parking will eventually reduce commuting time and GHG emissions. To be fully implemented, a smart parking system requires digital technologies and infrastructures such as in-ground or surface level magnetic parking sensors; smart parking meters with wireless connection and the ability to accept various forms of payment; smartphones for booking spaces; LED signs to indicate parking availability/ direction in garages. Los Angeles and Boston offer two successful examples of the implementation of smart parking systems:

- **Los Angeles:** the Los Angeles Express Park application uses parking sensors, dynamic pricing that reacts to demand, a parking guidance system and a mobile app that supplies real-time information about parking availability. The app itself also provides support for mobile payments, current rate, payment methods, voice guidance to parking areas and available spaces with the option to filter parking searches by permit type.
- **Boston:** Boston's smart parking system works in a similar manner and aims to connect drivers with vacant spaces and optimise their usage by means of real-time information and dynamic pricing. The initiative seeks to reduce congestion by shortening the time it takes to find a parking space and encouraging the use of different transport modes.

Bike-sharing accounts for only a fraction of current growth in shared- and micro-mobility forms of transport. In this context, new forms of mobility relying on electric fleets (e.g. e-bikes, e-mopeds), will also play a crucial role in further reducing GHG emissions. The micro-mobility market is expected to increase significantly, since it is solving many of the main problems facing today's cities: indeed, 46% of all journeys in urban areas are below 5 km and 60% of all journeys are below 8 km, and are thus a good match for the average journey distances of micro-mobility offerings such as e-mopeds, e-scooters and e-bikes. Also in this space, digital technologies act as key enablers to full utilisation of these services: transport operators need to ensure that adequate digital infrastructure and mobile applications are in place, to enable users and employees to interface with the system. On the one hand, advanced, effective digital apps need to be in place for travel bookings, information, prices and payment in order to streamline the user experience. On the other, the same apps with different features are needed to enable transport operators to remotely control ongoing operations and intervene when appropriate – this is particularly applicable for operators relying only on free-floating fleets to monitor, for example, locations, battery levels and operating problems.

Conclusion

The final combination of the above-mentioned digital technologies and infrastructures for smart mobility, coupled with additional applications deployed for security, healthcare, energy, water and waste (e.g. smart surveillance, real-time crime mapping, data-driven building inspections, telemedicine, remote patient monitoring, home energy automation systems, water consumption tracking, optimisation of waste collection routes, and others), will eventually help create "digital twins" of cities. Digital twins are a digital representation of a physical asset, which leverages digital technologies (e.g. 5G technologies) to collect, aggregate, monitor and analyse data, using cloud-edge computing, thus providing municipalities with valuable insights for urban planning.

All in all, reducing the environmental impact of the overall transport sector is among the key priorities on stakeholders' agendas. Within this context, digital technologies and infrastructures will act as critical enablers to foster the sustainable transition, both in urban and extra-urban areas. Whereas some applications are already widely implemented around the globe with positive empirical evidence, others still need a further push to secure their deployment. Nevertheless, in all circumstances, clear coordination, communication and a joint approach between all stakeholders (e.g. municipalities, technology manufacturers, transport service providers and end users) are essential to ensure effective and timely implementation of such beneficial solutions for environmental sustainability.

PART II
COUNTRY FOCUS

8. Promoting the EU's Approach to Sustainable Infrastructure at the Global Level

8.1 The European Strategy for the Green Transition

Manfred Hafner, Michel Noussan, Pier Paolo Raimondi

The European Union plans to become a carbon-neutral economy by 2050, in line with its commitments to global climate action under the Paris Agreement.[1] This strategy is known as the European Green Deal,[2] and in addition to reaching net-zero emissions it aims at ensuring that economic growth is decoupled from the use of resources. The complexity of this challenge requires a contribution from all the sectors of the economy, and multiple solutions will be needed to achieve this long-term objective. The deployment of low-carbon technologies will need to be backed by energy efficiency measures, in addition to actions focused on final energy consumption, targeting users' behaviour and demand management. In parallel to these environmental goals, which are at the heart of the European Green Deal, the EU is also

[1] European Commission, Climate Action, "2050 long-term strategy".

[2] European Commission, "A European Green Deal. Striving to be the first climate-neutral continent".

strongly pushing for a just transition, ensuring that all citizens are provided with an equitable access to energy and mobility, and that no one is left behind in the process. The European Green Deal aims at supporting the EU in becoming the first climate-neutral bloc in the world by 2050. In addition to climate action, it also includes other policy areas: clean energy, eliminating pollution, sustainable industry, mobility and agriculture, building and renovating, from farm to fork and biodiversity.[3]

The European Green Deal was presented by the European Commission's (EC) newly appointed President Ursula von der Leyen in December 2019, but in the months that followed the Covid-19 pandemic hit European countries hard, diminishing interest in the plan in light of the pressing need to support the EU economies hurt by the pandemic. However, a large majority of countries supported a combination of measures to couple support for economic recovery with the fight against climate change. In July 2020, the European Council agreed on a massive EU recovery fund of €750 billion, to support Member States in reacting to the economic and social damage caused by the Covid-19 pandemic.[4] This stimulus, named NextGenerationEU, also aims at supporting EU countries in their shift towards more sustainable and resilient economies and societies, thanks to the deployment of clean energy and digital technologies. The core of the NextGenerationEU is the Recovery and Resilience Facility,[5] an instrument that will allow Member States to access €672.5 billion in loans and grants that will be used to support reforms and investments after the approval of national recovery and resilience plans. Each plan will have to include at least 37% of expenditure on climate investments and reforms, and a minimum of 20% of expenditure to foster the digital transition.

Finally, a specific strategy has been developed for the transport sector. The transport sector is responsible for a quarter of CO_2

[3] Ibid.: Policy areas.

[4] European Commission, "Recovery Plan for Europe".

[5] European Commission, "The Recovery and Resilience Facility".

emissions in the EU, and it represents the only sector where emissions have regularly increased in recent decades. In 2020, the European Commission launched its European Sustainable and Smart Mobility Strategy,[6] with 82 initiatives in 10 key areas, and proposing a number of specific milestones between 2030 and 2050 related to various transport segments and modes. These milestones include at least 30 million zero-emission cars on European roads by 2030 (in addition to a large-scale deployment of autonomous vehicles), and a carbon-neutral short-haul collective travel by the same year. Zero-emission market ready technologies are expected by 2030 for marine transport and by 2035 for large aircrafts. By 2050, in addition to expecting almost all road transport to be zero-emission, the strategy explicitly mentions “a fully operational, multimodal Trans-European Transport Network (TEN-T) for sustainable and smart transport with high-speed connectivity”.

Infrastructures, Industry and Technologies

The path towards a low-carbon society requires a systemic approach, encompassing energy generation, conversion, transmission and distribution, as well as final energy consumption in industries, buildings and transportation. The deployment of clean technologies, in addition to a strategic development of the relevant supply chains, will also require new infrastructures and upgrading and improving existing ones. A key element of the EU decarbonisation strategy is a massive upscale of low-carbon renewable-based electricity generation combined with a strong increase in the electrification of all final sectors.

Many EU countries have already invested in significant deployments of renewable power generation, mostly in solar

[6] European Commission, Mobility and Transport, Mobility Strategy, “A fundamental transport transformation: Commission presents its plan for green, smart and affordable mobility”.

and wind power. As of 2019, EU-27[7] member countries have a wind power capacity of 167 GW (up from 71 GW in 2009) and a solar power capacity of 120 GW (up from 17 GW in 2009).[8] However, if the EU is to reach its decarbonisation targets, both sources still need to show additional upscaling in the coming decades. According to the ENTSOs[9] EU scenarios,[10] total wind power will need to reach 390-400 GW by 2030 and 530-610 GW by 2040 (of which 80-140 GW offshore wind, up from 12 GW in 2019). Solar power deployment will also need to continue at a strong pace, reaching 270-410 GW by 2030 and 400-685 GW by 2040, depending on the scenarios. In addition, other low-carbon sources for power generation will also need to play an important role, including hydro, bioenergy, geothermal and fossil-based plants equipped with carbon capture and storage (CCS). An additional contribution could come from nuclear power in some countries, though the overall role of nuclear in the EU is still unclear in the long-term, mainly due to different and potentially changing strategies and opinions in Member Countries. Indeed, the energy mix is a prerogative of Member Countries.

Electricity from renewables, renewable gas (either via bio-methane or synthetic methane produced from electrolysis) and decarbonised gas (hydrogen produced via pre- or post-combustion carbon capture and storage from natural gas) may all play a role in a future low-carbon energy system.

Over the next decades, the EU could also benefit from harvesting the huge and still untapped offshore wind potential available

[7] EU-27 refers to the EU without the UK which had left the Union on the 31st of January 2020.

[8] Eurostat data: https://ec.europa.eu/eurostat/data/database.

[9] ENTSOs is the combination of both ENTSO-E and ENTSO-G, respectively the association of European electricity and natural gas transmission system operators. In the framework of their last Ten-Year Network Development Plans, which have been developed jointly in 2020, ENTSO-E and ENTSOG have defined two top-down future scenarios that are consistent with the efforts of the EU-27 to reduce emissions to net- zero by 2050.

[10] Entsog Entsoe, *TYNDP 2020 Scenario Report*, June 2020.

in Northern Europe. The European Union has an enormous deep offshore potential, with high-quality winds in the North Seas, which includes the North Sea, the Baltic Sea and the Irish Sea. According to a 2019 study[11] by the International Energy Agency, the EU offshore holds the potential to satisfy 11 times the present EU electricity demand.

The availability of high-quality energy transmission networks (electricity, gas, hydrogen) is of paramount importance to optimise the matching between energy generation and energy consumption, together with the development of smart and digital solutions and energy storage options. In addition, and specifically for electricity networks, distribution grids need to be upgraded to guarantee the flexibility and capacity required by additional power demand in final sectors. Specifically to support electric mobility and the increase of electric vehicle shares, a wide deployment of public charging infrastructure will be required, especially in dense urban environments. Some consumer groups, environmentalists and carmakers argue that the EU should reach 1 million public EV chargers by 2024, and 3 million by 2029,[12] up from the existing 225,000 charging points as of 2020.[13]

The final step of this strategy is the support towards higher electrification rates of final uses. The most significant applications are building heating, via heat pumps, and electric mobility. This will require dedicated policy support towards new technologies, which are not yet competitive with fossil-based solutions in most countries. Policies that are able to quantify and internalise the cost of environmental impacts and externalities, such as the EU Emissions Trading System

[11] International Energy Agency (IEA), Data and Statistics, *Global Offshore Wind Outlook*, 2019.

[12] "EU should target 1m EV public chargers by 2024, say carmakers, environmentalists and consumer groups", *Transport and Environment*, 10 February 2021.

[13] European Alternative Fuels Observatory

(ETS),[14] are of paramount importance in this process. And so are policies that are able to support citizens in shifting towards cleaner technologies, by limiting inequality and energy poverty.

However, to reach full decarbonisation, some sectors will not be easy to electrify. Therefore, other solutions are required, including hydrogen or CCS. This will be particularly true for industries that require very high-temperature heat, and some transport segments such as shipping and aviation, where the current and expected energy densities provided by electric batteries will not be enough to meet the required level of performance.

In addition to deploying infrastructure for energy generation, transmission and final consumption, the EU is also developing strategies and specific industrial policies to develop and improve some of the key industrial sectors required for a low carbon transition. EU industrial policies include actions targeted towards key sectors for the energy transition, including the Raw Materials Alliance, the Battery Alliance and the Clean Hydrogen Alliance. These strategies have the objective of facilitating interactions between different stakeholders in EU countries and supporting the development of competitive supply chains in sectors that are crucial for the energy transition. This takes into account security-of-supply considerations for certain critical components needed for the energy transition, and economic considerations including domestic job creation. In some cases, such as for electric batteries, the EU aims at becoming one of the world leaders in sustainable manufacturing and use of such a key enabling technology.

Finally, it is important to remember the roles of energy efficiency and energy demand management. Developing a sustainable and decarbonised energy system is not only a matter of technological shift; it also needs to involve a new paradigm of energy consumption, which must aim at reducing demand and increasing efficiency. Such a new paradigm will require non-technical actions that affect regulations, energy markets as well

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[14] European Commission, "EU Emissions Trading System (EU ETS)".

as citizens education and behaviours. As demonstrated in some EU countries (e.g. the yellow vests – *gilets jaunes* – movement in France), it is important that the different strata of citizens are actively involved in such a challenging transition, to ensure an effective, equitable and just energy transition and to ensure that no one feels left behind.

Geopolitical Implications

The European Green Deal also encompasses relevant geopolitical dimensions. Due to its global scope, energy has always gone hand in hand with international relations. The ultimate EU goal to become the first climate-neutral continent by mid-century will impact the EU's energy dependence, which currently relies on oil and gas imports (mainly from Russia, North Africa and – to a minor degree – some Middle Eastern countries). Due to limited availability of domestic hydrocarbons, the EU has historically relied on energy imports, significantly shaping its energy security concerns. Today, the EU imports 87% of the oil and 74% of the natural gas it consumes.[15] The biggest energy security concerns are related to natural gas, notably *vis-à-vis* Russia, which represents the bulk of EU gas imports, mainly through pipelines. In contrast, Norwegian energy imports, though not negligible, are not considered problematic from a security of supply perspective. Gas trade relies very heavily on the availability of transport infrastructure, the control of which yields power. While oil is a truly global market, in Europe gas is mainly a regional market based largely on pipelines from Russia, Norway, Algeria, Libya and Azerbaijan. Only recently, thanks to the combination of the establishment of a functioning and interconnected internal European gas market, and of the large scale development of a global LNG trade, which allows

[15] M. Leonard, J. Pisani-Ferry, J. Shapiro, S. Tagliapietra, and G. Wolf, *The geopolitics of the European Green Deal*, Bruegel and European Council on Foreign Relation, Policy Contribution, no. 4/21, February 2021.

gas to slowly becoming more globally interconnected, has the European security of supply risk related to gas declined.

With the implementation of the European Green Deal, the nature of the EU's energy interdependence will progressively undergo important changes. In the medium term the EU may need to increase gas imports to meet its energy demand because of the implementation of climate policies (due to the necessary phasing out of coal-based power generation, which has twice as high CO_2 emissions for each kWh produced) and the reduction of domestic gas production. In the longer term (beyond 2030) the EU fossil fuel demand and, consequently, imports are expected to shrink significantly, affecting its traditional suppliers in North Africa (i.e. Algeria and Libya), Norway and Russia. Compared to those countries, other major oil and gas exporters, such as those in the Middle East, will suffer less from European decarbonisation policies both due to low EU imports from the region and their more diversified export portfolios, in particular to Asian countries, where energy demand (including fossil) is still expected to grow extensively for some time, reflecting expected economic growth rates. The commitment to a higher share of renewables in the EU energy mix serves thus not only the pursuit of carbon neutrality, but also the increase of EU's energy resilience and security of supply.

However, the EU may be exposed to several potential new security concerns over new energy sources and materials. At the domestic level, these include potential instability of the electricity grids as they rely more and more on variable renewable sources, while internationally they may interfere with the supply chains of critical equipment and materials such as rare earth elements (REEs). Indeed, clean energy is not immune to energy and geopolitical (inter)dependence. The European Green Deal will surely reduce European dependence on fossil fuels, but it will amplify European dependence on components for renewable energy, from minerals to manufacturing.

Currently, the EU is between 75% and 100% reliant on imports for most metals essential to clean energy technologies.

For example, China provides 98% of the EU's supply of REEs, Turkey provides 98% of the EU's supply of borate, and South Africa provides 71% of the EU's needs for platinum and an even higher share of the platinum group metals iridium, rhodium, and ruthenium[16]. The EC estimated that for EV batteries and energy storage, the EU would need up to 18 times more lithium and 5 times more cobalt in 2030, and almost 60 times more lithium and 15 times more cobalt in 2050 compared to the present. To address these potential supply issues, the EC launched the European Raw Materials Initiative in 2008. In 2020, the EC outlined the necessity to engage in strategic partnerships with resource-rich third countries to enhance supply diversification, foster recycling processes to reduce dependency on primary critical raw materials, and strengthen domestic sourcing and processing in the EU.[17]

The EU is committed to lead in key sectors of the future low-carbon economy. In March 2020, the EC launched a New Industrial Strategy for Europe, which lays the foundations for an industrial policy that is intended to make EU industry more competitive globally in key sectors and enhance Europe's strategic autonomy.[18] This strategy envisages the use of industrial alliances as a key component for the achievement of the proposed goals. Among great powers, there is a growing competition to become technological and industrial leaders for the energy transition. Currently, China holds a dominant role in the production of low-carbon energy sources: it produces more than 70% of the world's solar modules and it is home to nearly half of the global wind turbine manufacturing capacity.[19]

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[16] European Commission, Brussels, COM(2020) 474 final, "Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability", 3 September 2020.

[17] Ibid.

[18] European Commission, COM(2020) 102 final, "A New Industrial Strategy for Europe", Brussels, 10 March 2020.

[19] "The geopolitics of energy: Out with the old, in with the new?", *forum*, The Oxfrod Institute for Energy Studies, no. 126, February 2021, p.14.

In May 2021, the Commission updated the 2020 EU Industrial Strategy in response to the economic, industrial, energy and geopolitical consequences of the Covid-19 pandemic. The pandemic has explicitly brought to light important European vulnerabilities regarding critical and strategic supply chains. Therefore, the new main theme is the reduction of technological and industrial dependencies from external actors, primarily China. The EU aims at increasing its strategic autonomy through the establishment of new and diversified supply chains, fostering domestic industrial and technological capacity, as well as strengthening its green and digital transitions, mainly within the framework of the Next Generation EU.[20]

Hydrogen illustrates this new, dual essence of energy geopolitics within the global energy transition. The EU seeks to become a leading player in hydrogen to meet its climate targets and it also sees hydrogen as a sector in which to enhance its technological leadership. In July 2020, the EU launched its Hydrogen Strategy, which envisages an important role in the future European energy mix. To support this target, the European Commission foresees massive investments (up to €180-470 billion by 2050) for green hydrogen and a much smaller amount (€3-18 billion) for blue hydrogen, stressing its political priorities. Hydrogen has drawn major political support in Europe both at the continental and national level. The EU is committed to become a technology maker rather than being a technology taker. Its goals for hydrogen are shaped by its painful experience in solar PV manufacturing, which was developed in Europe at high cost only to later move to China.[21]

The EU may encounter some obstacles in producing all its green hydrogen needs, due to limited available renewable energy resources compared to its energy demand and its high

[20] European Commission, Com(2021) 350 final, Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee to the Regions, Brussels, 5 May 2021.
[21] S. Amelang, "Who will be the Hydrogen superpower? The EU or China", *EnergyPost.eu*, 31 August 2020.

population density. From an energy efficiency point of view it makes more sense to use the limited renewable energy potential to fully decarbonise the power sector first, while at the same time importing green (i.e. renewable energy based) hydrogen from better endowed regions. Several EU countries have plans to import green hydrogen produced from cheap renewable energy sources in regions with a very high solar radiation (e.g. the deserts of North Africa and the Middle East). While the EU could in part take advantage of the already existing energy infrastructure from these countries to import cleaner energy sources to meet its ambitious climate and energy targets, there are also plans to build a dedicated infrastructure to reach an import capacity of 40GW of hydrogen to Europe by 2030.[22]

The EU supports the development of clean energy technologies in its Southern and Eastern neighbourhoods. These areas present a favourable renewable potential; for example, North African countries hold significant solar and wind resources. By supporting clean energy technologies in these areas, the EU could meet a multiple objective: achieving collectively and effectively a broader decarbonisation, ensuring cost efficient clean energy imports, and contributing to the socio-economic development of its neighbourhood regions, thus promoting stability and peace as well as limiting migration pressures. At the same time, the EU would also enhance its soft power and geopolitical footprint in these vital neighbourhood areas, which are strategically relevant for European countries and where other extra-EU countries are trying to increase their influence.

The EU is committed to be a leading power in the fight against climate change. However, given the global nature of the threat, the EU needs to engage with other countries in order to affectively achieve its goal. This is why the EU pursues a proactive global "climate diplomacy".

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[22] A. van Wijk and J. Chatzimarkakis, *Green Hydrogen for a European Green Deal A 2x40 GW Initiative*, Brussels, Hydrogen Europe, 2020.

Conclusion

The EU has emerged at the vanguard of global climate and energy policy. Its climate ambition has not been weakened by the unprecedented health and economic crisis; on the contrary, the EU announced a reinforced emissions reduction target of 55% (from 40%) by 2030 below 1990 levels.

The strong political commitment surely represents a major opportunity for the decarbonisation of the European economy and society. The EU and its Member States have focused and aligned their economic stimulus plans to climate and decarbonisation measures. In this sense, the European countries have reiterated their political will to rescue and rebuild their economies to reflect their climate promises. The renewed role of the public sector, on the heels of the Covid-19 crisis, presents a major opportunity to boost such a major transformation. Moreover, the EU is working on the European Climate Law, which sets the target of net zero greenhouse gas emissions by 2050 as a legal obligation for the EU and its Member States.
Nonetheless, achieving carbon neutrality by 2050 still requires massive and substantial changes to be implemented. Translating the general political commitment on decarbonisation into actual implementation still faces some challenges. Firstly, energy is a shared competence between the European institutions and Member States. This may slow down the implementation of the necessary policies and actions to reach net zero target because of specific socioeconomic and political considerations at the local level. Some countries, which depend on polluting energy sources for their energy and economic system or simply have different socio-economic priorities, may express their opposition, hindering the overall success. Moreover, some sectors and portions of the population may manifest their discontent towards climate-friendly policies, as already shown in the case of the *Gilets Jaunes* movement in France. Since energy decarbonisation is a policy-driven process, popular turmoil may undermine political commitment.

The ongoing major transformation in the European power sector represents a successful and encouraging example; however, it is not enough. The EU will need to increase renewable energy sources to replace coal in the next two decades. Moreover, to achieve its climate targets, the EU needs to step up efforts in all sectors, especially in transport and in hard-to-abate sectors. Transport emissions have continuously risen over the last decades, making it important to specifically tackle emissions from this sector, which account of about a third of total EU emissions. However, massive investment is needed to deploy the necessary infrastructure to electrify the transport sector. Furthermore, an additional effort will be essential to decarbonise heavy industry, underpinned by rising carbon prices and development of hydrogen technology. Nevertheless, a surge of EU carbon prices, compatible with decarbonisation pathways, poses a challenge to European industry competitiveness compared to other regions if they do not implement the same kind of carbon pricing. To offset this issue and to pursue a proactive climate diplomacy, the EU is considering the introduction of a carbon border adjustment mechanism (CBAM). However, this option has already encountered (geo)political issues and opposition from major world's economies, with the no exception of Europe's ally, the US, which considers a carbon tax as a last resort.

The European Green Deal represents an opportunity for the EU to enhance its geopolitical role in the energy transition. EU Commission President von der Leyen expressed her ambition to lead a "geopolitical Commission", and climate certainly represents an opportunity in this sense. With the US and China also aspiring to become the leading global powers in the energy transition and in key economic, technological and industrial sectors of the low-carbon economy, the competition in developing low carbon technologies and to access and control critical mineral resources needed for the energy transition may create new rivalries among global powers.

The EU will need to step up its climate diplomacy efforts if it is to succeed in bringing other major economic powers and the rest of the world along a cooperative and mutually beneficial decarbonisation path.

8.2 The External Dimension of the EU's Transport Infrastructure Policy

Stefano Paci

The European Green Deal (EGD) sets out the EU's ambitious goal of becoming climate-neutral by 2050.[1] In accordance with its international commitments and in view of an intertwined economic and geopolitical context, the European Commission is devising pertinent policies and initiatives, including in transport infrastructure. This sector plays a critical role, contributing around 5% to EU GDP and employing more than 10 million people in Europe, driving European business and global supply chains, but not without costs. Reviewing the overall efficiency of transport infrastructure and promoting a new approach to mobility is high on the European and global political agenda.

The rapid spread of digitalisation (the digital revolution) is spurring on this endeavour through new, smarter mobility systems, based on automation with a shared and collaborative economy and platforms. The post-Covid-19 perspective is adding momentum: "building back better" – including through enhanced, safer, more accessible and smart connectivity – is one of the policy priorities for a swift economic recovery recently discussed at the G7.[2]

During this "big bang" moment for the transport sector, the European Commission adopted its Sustainable and Smart Mobility Strategy (SSMS), outlining how the EU intends to create an irreversible shift to zero-emission mobility while

[1] Net-zero GHG (greenhouse gas) emissions by 2050 and reducing net GHG to 55% below 1990 levels by 2030 – European Commission, "The European Green Deal", COM(2019)640.

[2] G7 Leaders' Summit Communiqué (Carbis Bay, UK, 11-13 June 2021): "Our Shared Agenda for Global Action to Build Back Better".

making our transport system more efficient and resilient.[3] Its pragmatic roadmap (82 actions and flagship initiatives) entails that there is no single "silver bullet" but rather milestones illustrating the level of ambition of the European transport system for the next 10-30 years, ranging from zero-emission transport modes to renewable and low-carbon fuels and the infrastructure to keep vehicles running on them. The green transition should and has to go hand in hand with reforms in the transport sector. It is equally clear that, while no specific "external dimension" action is listed in the roadmap, the SSMS essentially needs to be implemented not just in Europe but also internationally. As the EU will not be able to decrease global emissions by acting unilaterally, in the same way, developing a sustainable connectivity policy and infrastructure can only be successful if pursued beyond the EU as well. A comprehensive policy approach to transport infrastructure is achieved also through the exclusive competences on trade and competition matters as well as initiatives on industry, environment and ICT domains (paragraph 1).

From a geographical perspective, the promotion of sustainable infrastructure and connectivity is a key component of the various EU regional strategies. The ongoing transport cooperation and relevant policy initiatives (notably covering the neighbouring regions) entail the need to invest in both regulatory frameworks and physical infrastructure.[4] Linked to this vision, the programming process for the 2021-27

[3] European Commission, "Sustainable and Smart Mobility Strategy - putting European transport on track for the future", COM(2020) 789, Brussels, 9 December 2020.

[4] European Commission, Joint Communication "Towards a comprehensive Strategy with Africa", JOIN(2020)4; European Commission, Joint Communication "Eastern Partnership policy beyond 2020", JOIN(2020)7; European Commission, "An Economic and Investment Plan for the Western Balkans", COM(2020)641; European Commission, Joint Communication "Renewed partnership with the Southern Neighbourhood - A new agenda for the Mediterranean", JOIN(2020)2; EU-India Leaders' Meeting (8 May 2021), Joint Statement; EU-US Summit, 15 June 2021, Statement.

financial framework includes new strategic instruments (e.g. Neighbourhood, Development and International Cooperation Instrument (NDICI) – Global Europe for the next period 2021-27 and the EU External Investment Plans[5]) addressing infrastructure projects based on priorities identified and agreed with partner countries and regions. They aim to complement private investment and promote cooperation between private investors, European and international financial institutions, national private banks and development banks (paragraph 2).

Key Policy Areas Supporting the EU as the World's Sustainable Connectivity Hub

In order to enable the shift towards more sustainable transport links both internally and externally, the SSMS firstly calls for a necessary upgrading of the EU's Trans-European Transport Networks (TEN-T) infrastructure. While much progress has already been made since the adoption of the TEN-T Regulation in 2013, filling the "green and digital transformation investment gap" for the EU's internal market and beyond, notably in the neighbouring regions, would strengthen the EU's cross-border connectivity and enable interoperability between the TEN-T and the networks of third countries. The existing provisions on neighbouring countries[6] allow the Union to support, including financially, projects of common interest and adopt so-called indicative TEN-T maps, with a view to extending the TEN-T to these partners. The technical identification and political validation of such extended networks is not only the basis for regional integration at the EU borders, but also

[5] On 9 June 2021, the European Parliament and the Council of the EU adopted the Regulation on the "Neighbourhood, Development and International Cooperation Instrument (NDICI) – Global Europe" with an overall allocation of €79.5 billion for 2021-27.

[6] Article 8 of the "TEN-T Regulation" (Reg. EU/1315/2013) provides for cooperation between the Union and third countries.

provides the EU's partners with an essential tool for planning and prioritising investment. The Union has adopted indicative TEN-T maps for the European Economic Area (Norway, Iceland and Liechtenstein), Switzerland, the Western Balkans, the Eastern Partnership and Turkey (comprehensive network). Negotiations are ongoing with the South Mediterranean Countries.

The Commission's Work Programme for 2021 includes plans to review of the TEN-T legislative provisions (last quarter 2021), aimed, amongst other things, at improving links with the neighbouring third countries.

Modal shift is also a priority of the SSMS: railways should play a central role both internally and internationally and the EU has designated 2021 as the European Year of Rail to improve visibility of one of the most sustainable, innovative and safe transport modes. Traffic on high-speed rail should double by 2030 and triple by 2050, while rail freight traffic should increase by 50% by 2030 and double by 2050. Several initiatives are in the pipeline, including boosting long-distance and cross-border rail passenger services, looking at high-speed and high-performance train services (better connections for passengers between main urban nodes) and considering night train services as a complement to the EU high-speed rail network. Of course, the appropriate infrastructure will need to be in place for these objectives to be attained. This may also mean reinforcing certain infrastructure standards and quality requirements in order to ensure a fully interoperable network favouring a modal shift to this sustainable mode. This will start with the rapid roll-out of ERTMS, the European signalling and train control system, but would eventually encompass all aspects of train and network automation and traffic management.

Infrastructure development will also focus on digitalisation (naturally going hand-in-hand with decarbonisation) to ensure that the logical outcome of supporting new digital innovations will be a greener, smarter and more resilient mobility system. Specific attention will be given to the increased role of functioning urban nodes for the overall functioning of a multimodal network (e.g. focusing on the last mile of a journey for passengers and goods).

Making European transport infrastructure sustainable, smart and resilient also entails ensuring undistorted international competition and reciprocity in the priority areas identified by the SSMS. EU trade policy plays a significant role in recalling that the EU's openness to international trade and foreign investments comes with specific attention to distortive effects on competitiveness and the EU level playing field, notably when sustainability principles are also at risk. In particular, the EU welcomes foreign direct investment (FDI) from external partners, including in TEN-T projects, but of course on condition that EU rules are respected and applied, in terms of public procurement, competition, environment and interoperability rules and standards. The 2019 FDI Screening Regulation established a cooperation mechanism between Member States and the Commission in order to identify risks from FDI related to security and public order, in particular in TEN-T projects.

Promoting the EU as the World's Sustainable Connectivity Hub with Third Countries/Regions

Sustainable infrastructure links at the EU's borders

The SSMS sets out that the EU will seek to further deepen sustainable connectivity in different sectors with key partners in the region through existing and well-functioning cooperation frameworks, such as dialogues, agreements, technical cooperation and economic diplomacy.

In the area of infrastructure, the focus is on the neighbouring regions, where enhancing sustainable connectivity is a strategic objective of the EU. The EU's Economic and Investment

Plan in the Western Balkans[7] aims to pave the way for the long-term economic recovery of the region and foster regional economic integration, including through a green and digital transition. This support would be largely directed towards sustainable transport connectivity (with three flagship transport infrastructure initiatives), considered a strategic area for economic development. The extended TEN-T network acts as the reference point for infrastructure investments in the region. More than €1 billion (grants) was allocated to infrastructure development through the Western Balkan Investment Framework (WBIF) in the period 2014-20. Appropriate reforms in the transport sector and "soft measures" to ensure seamless transport will be important to help reconnect the Western Balkans and the EU. Resolving administrative bottlenecks, uncoordinated practices and a lack of data interchange are low-hanging fruits. The Transport Community Treaty, which entered into force in 2019, supports the progressive integration of transport networks based on relevant EU legislation, including in the areas of technical standards, interoperability, safety, security, traffic management, competition, social policy, public procurement and environment.

As part of the new Eastern Partnership framework (EaP), the Commission intends to put forward an Economic and Investment Plan for EaP that will invest in enhanced transport connectivity. Priority would be given to strengthening core transport links through the extended indicative core TEN-T network, including connections across the Black Sea. Improved key air, road, rail, maritime and inland waterway connections and development of logistics centres will stimulate sustainable economic development, market integration and cross-border trade within the region and between the region and the European Union. Within this broader framework, the existing Indicative TEN-T Investment Action Plan will be updated, major investments will be prioritised, and the Investment

[7] See footnote 4.

Plan is expected to mobilise additional financial sources. Infrastructure developments will be accompanied by initiatives aimed at improving road safety, developing smart transport and sustainable urban mobility.

The shared objective with the Southern Neighbourhood partners is to set up a safe, secure, sustainable and efficient transport system based on harmonised transport standards and an integrated multimodal euro-Mediterranean transport network. In terms of infrastructure, joint technical work has been underway since 2013 to identify an indicative regional map of the trans-Mediterranean transport network (TMN-T) to be connected to the TEN-T. The priority in the region will remain the swift development of the TMN-T supported by transport policy reforms identified jointly under the Regional Transport Action Plan (RTAP). The objective is also better access to financing support, including the new NDICI's approach for the period 2021-27 (grant funding as well as blending grants with loans from European and International Financing Institutions).

Connectivity Beyond the Neighbouring Areas

Beyond its immediate neighbours, the EU is actively engaging to deepen transport relations, including on transport infrastructure, with key strategic partners and international organisations, and continues to further develop links with new international partners, such as high-growth and emerging economies. As the EU's internal market guarantees non-discrimination and a level playing field for enterprises and promotes an open and transparent investment environment (while protecting critical assets), the EU has a clear interest in continuing to promote open and transparent procurement processes where companies should enjoy a level playing field in the light of internationally agreed practices, rules, conventions and technical standards, supported by international organisations and institutions. Close dialogues and cooperation contribute to efficient connections and interoperable networks as well as to address and focus the mobilisation of available resources for the required investments.

In light of the 2018 EU Strategy on Connecting Europe and Asia, the Commission continues to engage with key Asian partners covering not only specific transport modes (land/rail, sea and air) but, importantly, the horizontal issues underpinning all of them, such as sustainable connectivity (in its broadest sense, including environmental, social, economic financial and fiscal sustainability) involving all transport modes (thus promoting multimodality).

A close and continuous dialogue is taking place with Japan, the Association of South East Asian Nations (ASEAN), and exchanges at the technical level are increasing with the Republic of Korea and Australia. Through the EU-China Connectivity Platform (established in 2015), regular exchanges on transport infrastructure policy and development plans are taking place with a view to identifying and defining possible synergies between the EU's TEN-T and China's Belt and Road Initiative (BRI). Both sides are preparing to launch a Joint Study on Sustainable Railway-based Transport Corridors between Europe and China, as agreed in the 2019 Summit of EU-China leaders. As stressed at the May 2021 EU-India Leaders' meeting, the EU is ready to explore further concrete cooperation with India on matters of common interest such as the greening of the railways, ports and shipping sectors, and the decarbonisation of civil aviation, in addition to the upcoming work under the sustainable and comprehensive Connectivity Partnership launched at that meeting.[8]

As highlighted in the Communication "Towards a comprehensive Strategy with Africa", the EU has valuable expertise in regional infrastructure integration (discussed in a close technical dialogue under the Africa-Europe Alliance Transport Task Force in 2019), which is identified as a key element of the partnership for sustainable growth and jobs, especially in the

[8] See footnote 4.

context of the ongoing AfCFTA (African Continent Free Trade Agreement) process. In line with the principles set out in the SSMS, the EU is promoting cross-border connectivity at different levels (national, regional as well as with the African Union) based on rules that ensure fair and transparent competition, and on policies that ensure environmental protection, safety, security, as well as social and individual rights.

Enhanced cooperation on sustainable connectivity and high-quality infrastructure was also stressed in the recent Summit with the US. Based on the discussions launched within the G7 to build "back better for the world", the two sides are also committing to the shared objective of orienting development finance tools towards the range of challenges faced by developing countries, including in resilient infrastructure.[9]

Promoting Global Sustainable Infrastructure

In response to Covid-19, the Commission and the EU are actively involved in the discussions conducted within the G7 and the G20 to keep global transport routes and supply chains safe, open and secure. The SSMS lays the foundations for achieving a green and digital transformation and more resilience to future crises. Resilience should be based on efficient and interconnected multimodal transport systems, for both passengers and freight. Since the beginning of the Covid-19 pandemic, the EU has consistently prioritised a coordinated approach, as evidenced by the Green Lanes (keeping all freight, including medical supplies, flowing), focusing on support to passengers and crews (in particular, enabling safe crew changes and repatriation of seafarers in EU ports) and now with a framework of digital Covid certificates, to facilitate free and safe movement within the EU. Building on this approach, the EU also works closely with the International Maritime Organisation (IMO), the International Civil Aviation Organisation (ICAO)

[9] EU-US Summit…, cit., para.7.

and, of course, the World Health Organisation.

More broadly, it should be recalled that the EU will continue to promote global sustainable infrastructure also through its leading role in international negotiations on transport safety, security, digitalisation and the green transition in multilateral technical bodies and fora in the fields of aviation (ICAO), maritime transport (IMO), and on inland transport (Inland Transport Committee of the UNECE). Upholding the high-level EU approach in international standard setting bodies is highly instrumental to achieving the sustainable and smart transformation of international infrastructure.

Conclusion

2021 is a testing ground for Europe to operationalise its SSMS in the field of infrastructure. The EGD clearly states that such efforts should be a guiding principle in the EU's external relations. The SSMS recalls that promoting sustainable infrastructure beyond the EU's borders requires a common policy framework and language that is globally recognised by all actors. Under the umbrella of the EGD and its reference to the UN Agenda 2030 and the Paris Agreement, the SSMS sets out the EU's terms of reference for engagement in bilateral relations as well as in multilateral technical transport bodies with a view to reinforcing its position as the world's sustainable (transport) connectivity hub.

THE ITALIAN PLAN FOR A GREEN INFRASTRUCTURE TRANSITION

ISPI

The National Recovery and Resilience Plan (PNRR) represents a great occasion for Italy to strengthen its transition towards green infrastructure and transports, in line with the sustainability objectives of Next Generation EU. While only €25.4 billion of the €191.5 billion earmarked for the Recovery Plan would be invested in sustainable mobility infrastructures, the €59.47 billion allocated to the green transition include projects directly related to the domain of transportation. With over €62 billion to be managed,[1] the Italian Ministry for Infrastructures and Sustainable Mobility (MIMS), headed by the economist Enrico Giovannini, would be the main Ministry involved in terms of resources.

In terms of carbon emissions, Italy is performing remarkably well, with annual equivalent tons of CO_2 steadily below the EU-27 average during the last ten years. Italy is among the best performing large European economies in terms of renewable energy as well: in 2018, 17.8% of total energy consumption[2] was provided by renewables. In parallel with this rise in Renewable Energy Sources (RES), according to the IEA Italy has seen a decline in its use of coal and oil energy,[3] with an increase in natural gas, the least pollutant of hydrocarbons. In the transport sector, however, Italy faces some critical issues: it has a much higher ratio of cars per inhabitant than Germany or France (and almost half of vehicles are polluting ones), and lags behind in terms of railway infrastructure.[4] With only 28 kilometres of railways per 1000 inhabitants, compared to 41 in

[1] "Ten years to transform Italy. For the well-being of people and businesses, respecting tahe environment", Ministry of Sustainable Infrastructures and Mobility,

[2] Fonti rinnovabili in Italia e in Europa, GSE, 2018.

[3] International Energy Agency (IEA), Countries, "Italy".

[4] *Piano Nazionale di Ripresa e Resilienza*, #NextGenerationItalia, Italia domani.

France or 47 in Germany, Italy transports far less cargo by rail than other EU countries: in 2019, only 11.9% of goods in Italy were transported by rail, while the European average was 17.6%.

Mobility and Green Transition

To overcome this gap and foster a green transition in transports, the Italian National Recovery and Resilience Plan starts with the necessary energy supply and mobility strategy. Out of the 25.40 billion euros allocated for the green transition, 8.58 billion would be destined to sustainable local transport projects. This includes mass rapid transport, with 240 km of planned infrastructures in urban areas, and electric vehicles, with more than 20,000 recharge stations in both cities and major intercity roads. Out of those 240km, 11 would be destined to urban underground lines, 85 to trams, a once popular public transport system that is making a comeback all around Europe,[5] 120 to trolleybuses, and 15 km to cable cars. Trams, despite being a fairly old transport mode, are decarbonised while being both cheaper and faster to realise than underground metros. The investment in Italian public transport would not limit itself to new lines, but include an overhaul of the equipment as well. The largely outdated vehicle fleet would witness a major renewal, with a phase-out of the most polluting ones and the acquisition of zero-emission buses and trains. Around 3,360 new low- or zero-emission buses would be bought by 2026, along with 53 new trains and around a hundred train carriages built with recyclable materials and equipped with photovoltaic panels. The total allocation for those acquisitions would be of €3.64 billion, helping a much-needed renovation that would eventually reduce the use of private cars in favour of public transport, especially in major urban areas.

[5] A. Hernández-Morales and J. Posaner, "European cities revive tram networks to cut transport emissions", *Politico*, 7 May 2021.

The Role of Hydrogen

Hydrogen plays a key role in the Italian plans for green transition. The guidelines for the National Hydrogen Strategy provide an insight on the planned investments: up to €10 billion of investments, half of which would come from ad hoc funding, are planned to achieve the Government's objectives of emission reduction and increased hydrogen production capacity in Italy.

The Italian PNRR offers a more detailed account of the plans for hydrogen, both as an energy source and as a fuel for transportation. Overall, the plan dedicates a specific chapter to hydrogen investments, with a total of €3.19 billion covering hydrogen production, distribution, and final consumption, with a focus on rail and road mobility. The idea is to promote the production and use of hydrogen at a local level, making use of existing industrial areas. The concept of "*hydrogen valleys*" revolves around the requalification of dismissed industrial sites, which are already connected to the electric grid (in order to reduce costs), to produce hydrogen through excess renewable energy and to transport it to the surrounding industries or through the gas infrastructure, thus reducing transportation costs and emissions. This would happen primarily through so-called "blue hydrogen",[6] namely hydrogen produced from natural gas through a process that allows to capture and stock more than 90% of the CO_2 emissions created in the conversion from gas to hydrogen. The integration of industrial areas with the gas infrastructure would facilitate such processes. However, it should be kept in mind that blue hydrogen and Carbon Capture and Storage (CCS) can represent only a transitional phase, a bridge between "grey" and "green" hydrogen, entirely produced through renewables and electrolysis. Italy plans to reach 5GW production capacity of green hydrogen (electrolysis) by 2030, with a total penetration of hydrogen equal to 2% of final energy demand. While the goal might not appear particularly ambitious, the 5GW objective is the same as Germany's:

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[6] "Cingolani, per ecotransizione servono idrogeno blu e metano", *A&E Energia*, 5 May 2021.

within the EU, only France is aiming at a higher electrolysis capacity by 2030, with 6.5 GW expected.[7]

While hydrogen is a strategic resource in energy-heavy industry, the Italian Recovery Plan presents two key experimental phases for hydrogen in transportation: road and rail. Road use of hydrogen would be concentrated in long-distance truck transport, which is among the most polluting forms of transportation. The increasing competitiveness of low-carbon trucks, primarily fuel cells ones, would allow for a development in long-distance transport of goods in Italy. The Italian government plans to install a series of recharge and filling stations along the main routes, including the A22 highway, and close to the most important logistical hubs in the country. The resources allocated in the PNRR for hydrogen projects involving road transport is €230 million, for a total of around 40 stations to be created. This would be fully coherent with EU Directive 2014/94 on alternative fuels and with the European Commission's Hydrogen Strategy,[8] which, among other things, calls for the development of green corridors for hydrogen-propelled heavy trucks. According to the Italian PNRR, by 2030, hydrogen could cover 5-7% of the total energy demand for long-range trucks, with estimates for 2050 ranging from a minimum of 20% to a maximum of 80% in case of total decarbonisation.

The other primary application of hydrogen to transportation envisaged in the Italian PNRR is railways. In addition to its significant gap in rail infrastructures *vis-à-vis* the other main European economies, Italy also has an issue with train emissions. Around one-third of Italian railways, approximately 4.763 km out of a total 16.800 km, has diesel-powered trains,[9] due to the limited economic convenience of electrifying large tracts of rails, especially

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[7] S. Matalucci, "Italy targets 5 GW of electrolyzer capacity by 2030", *PV Magazine*, 30 November 2020.

[8] European Commission, Brussels, COM(2020) 301 Final, "A Hydrogen Strategy For A Climate-Neutral Europe", 8 July 2020.

[9] Ministero dello Sviluppo Economico, *Strategia Nazionale Idrogeno. Linee guida preliminari*, November 2020.

in the South. This kind of railway, which cannot be easily electrified, constitutes the perfect candidate for hydrogen-powered trains. Germany is now the only country in the world where a hydrogen train has passed the trial phase and has become operational,[10] with Italy and France planning to run experimental projects within the NGEU framework. This is all the more urgent considering that the Italian fleet of diesel trains is relatively old and would need to be substituted in the coming years, creating the perfect opportunity for a switch to hydrogen. While most non-electrified lines are located in the South, northern Lombardy also features among the candidates chosen by the Italian government for this trial, due to its mountainous nature and the large number of train users. In order to fully exploit economies of scale, priority would be given to those areas that can integrate hydrogen production and storage for both road and rail transportation. The €300 million that would be invested in the project would also include R&D elements, as well as storage systems, to create 9 stations along 6 rail lines. A first agreement was reached in 2020 between SNAM,[11] an Italian energy infrastructure company specialised in natural gas, and Ferrovie dello Stato, the main rail operator in Italy, to realise pilot projects on switching rail lines from fossil fuels to hydrogen.

Infrastructural Investments

The choice of changing the name of the Ministry of Infrastructure and Transports into "Ministry for Infrastructure and Sustainable Mobility" is a testimony to the commitment of Mario Draghi's Government to a green transition in infrastructure. An entire chapter, or mission, of Italy's National Recovery and Plan is dedicated

[10] T. Patel and Bloomberg, "A hydrogen-powered train will make transport history as Europe looks to become world leader in green rail travel", *Fortune*, 23 April 2021.

[11] "FS Italiane e Snam: al via collaborazione per promuovere lo studio dell'idrogeno nel trasporto ferroviario", Ferrovie dello Stato Italiane, 21 October 2020.

to infrastructural investment, concentrated on railway lines: out of a total €25.40 billion allocated, €24.77 billion are destined to railways, while the balance would support programs for road and transport safety.

Even though the resources allocated are high, parts of the planned investments are aimed at bridging the gap between Italy and its European counterparts (Germany and France) in the domain of rail transport. According to a 2019 Report by the European Commission on the state of transport in the Union,[12] the use of rail transport in Italy is lower than the EU average for both passengers and goods. This is due primarily to a poor integration of transport nodes, especially in the southern regions: the Report highlights that only 8% of ship berths in the South are connected with inland railways, against 48% in the North. Previous specific recommendations by the Commission have focused on Italy's necessity to reduce its car dependency and to improve the quality of its infrastructural network.[13] The PNRR contains detailed provisions to solve those issues, as well as to strengthen connectivity of main Italian cities with high-speed lines. Switching some of the passenger and merchandise traffic from road to rail would help reduce the carbon footprint of the Italian transport sector: it estimated that an increase from 6% to 10% of the share of passengers using rails would reduce CO_2 emissions by 2.3 million tonnes per year.

The perspective of the Italian railways investment is twofold, depending on the area of the country: in the South, the main goal is to increase capacity and expand long-distance lines, including high-speed trains (which currently reach only Salerno on the Tyrrhenian Sea, and are still absent on the Adriatic coast). In the North, where high-speed lines are already relatively well-developed, investments would concentrate on connectivity across the Alps with urban transport of large cities. In Southern Italy, the main high-speed lines

[12] European Commission, Mobility and Transport, *Transport in the European Union Current. Trends and Issues*, March 2019.

[13] "Italy: inadequate infrastructure holds back the economy", *WE Build Value*, 31 July 2019.

that would be created are Naples-Bari, Palermo-Catania-Messina in Sicily, and the completion of the Salerno-Reggio Calabria line, which would allow high-speed (AV) trains to cover the entire Tyrrhenian coast. The resources allocated to these new or upgraded lines amount to €4.64 billion. In addition to that, the Centre and South of Italy would also benefit by the so-called "*diagonal connections*", a critical issue largely due the complex topography of the Apennines. These lines would link the two opposite coasts of the country: Rome-Pescara, better links between Rome and Ancona, and increased line capacity linking Campania with Puglia. The total amount of expenditure for those links is €1.58 billion.

In the North, efforts would be concentrated in upgrading connectivity between the main passenger and cargo lines with urban centres, as well as improving connections with Northern Europe through the Alps. The planned projects include the Brescia-Verona-Vicenza line, where line capacity would be increased, a massive overhaul of links between Genoa, Turin, and Milan, as well as a development of the railway linking to the Brenner pass, the main gateway for Italian exports to Europe. The National Recovery and Resilience Plan allocates €8.57 billion for these projects. Additional railway investments are related to the strengthening of urban nodes, and regional lines, while Southern Italy would also receive specific funding to expand electrification of lines and increase resilience. Medium-range connectivity and integration of train lines with urban and suburban public transport is critical to reduce the use of private cars, making green transport a competitive alternative for commuters. This would be further helped by a strengthening of regional train lines, increasing their speed and capacity in close connectivity with high-speed infrastructures. Finally, Southern Italy would see some of its bottlenecks eliminated, with a significant modernisation and electrification of existing lines. Parallel to those measures, investments would also be directed towards the integration of ports into the rail infrastructure, a key concern for Southern Italian ports. This would also cover last-mile connections with airports such as Olbia, Trapani, and Brindisi. Finally, every train station in the South would receive an upgrade in terms of its accessibility, functionality, and connections with the surrounding areas.

Finally, maritime transports and ports are also included in Italy's PNRR, with a dedicated investment of €3,8 billion. The planned upgrade of Italian ports systems follows a double track: modernizing and improving the interconnections of ports, while reducing their environmental footprint. The Green Ports project would include nine different Port Authorities (located in the North and Centre regions) and support them in improving their energy efficiency and the use of renewables, as well as in mitigating their impact on local biodiversity and natural heritage. Parallel to this, Italy is also investing in cold ironing facilities and procedures to provide energy to ships at berth from shore plants, primarily using renewables instead of the highly polluting ships' fossil fuels generators.

The National Plan for Recovery and Resilience, within the framework of the Next Generation EU, is a unique opportunity to update the country's infrastructure endowment while improving overall competitiveness and boosting long-term economic growth. It will help citizens, industries and the public administration to reduce energy costs and improve energy autonomy. It is now crucial that European and national resources are invested in an efficient way that avoid overlap and waste of funds.

9. United States and Sustainable Transition: The Time for a New Green Federal Infrastructure Package

Lachlan Carey

In late March, President Joe Biden announced the American Jobs Plan (AJP), a sweeping package that dedicates over US$2 trillion towards repairing and upgrading infrastructure, revitalizing manufacturing, and valuing the care-giving economy. The AJP is a calculation that 2021 is not only the time for a green federal infrastructure package, but also for beginning a process of political and economic renewal driven, in part, by the transition to a net-zero economy. It is therefore as much a political calculation, riding on the president's ability to secure a popular mandate, as it is an economic one, investing in infrastructure that can cure some of the structural ills ailing the American economy. The AJP also seems to understand that no illness is more deadly, or the cure more promising, than the policies required to address climate change.

These ambitious goals have dramatically raised expectations of the new president. Newspaper columnists regularly compare Biden and his agenda to FDR and the New Deal, or LBJ and the Great Society.[1] Biden views himself as arriving "at an inflection point in American history" that can only be capitalized upon through the developmentalist approach of high public

[1] J. Alter, "How F.D.R.'s Heir Is Changing the Country", *New York Times*, 12 April 2021.

investment and widespread government intervention.[2] Unlike the market-oriented neoliberal mindset, developmentalism as a strain of political thought maintains that long-term, public investment has been responsible for the positive economic "inflection points" in American history.[3] Of note is its view of an economy and a society that is incomplete, whose market actors need direction, assistance, and guidance.[4]

Historically, developmentalism has often re-emerged in response to a crisis, and in many respects, this time is no different. When Joe Biden accepted his nomination as the Democratic candidate for President, he cast his ambitious agenda as a response to "[f]our historic crises. All at the same time. A perfect storm:" a global pandemic, a severe economic downturn, ongoing racial injustice, and the impending climate crisis.[5] The public investment philosophy of developmentalism is likely required in all four cases, but perhaps none more so than the historic, decades-long transition towards a zero-carbon future. The intergovernmental panel on climate change (IPCC), for example, warns that avoiding catastrophic impacts from climate change will require "systems transitions that are unprecedented in terms of scale", and though the AJP is certainly large, it is not clear that it is anywhere close to large enough.[6]

A new green federal infrastructure package is a necessary, if insufficient condition in meeting these climate goals in that it begins to revive the capacities of a developmentalist state.

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[2] J. Biden, "Remarks by President Biden on the Economy", The White House, 27 May 2021.

[3] J. Levy, *Ages of American Capitalism: A History of the United States*, Random House, 2021.

[4] S. Link and N. Maggor, "The United States as a Developing Nation: Revisiting the Peculiarities off American History", *Past & Present*, vol. 246, no. 1, February 2020, pp 269-306.

[5] J. Pramuk, "Read Joe Biden's full 2020 Democratic National Convention speech", *CNBC*, 21 Aug 2020.

[6] Intergovernmental Panel on Climate Change, *Special Report: Global Warming of 1.5 °C*, IPCC.

Such a state will require a strong political mandate, if for no other reason than to maintain high levels of public investment, particularly in the physical infrastructure and innovative capacities that will facilitate the technological transitions to a zero-carbon economy. The AJP is therefore necessary, in that these political, economic, and technological challenges are dynamic processes, requiring a catalyzing first step from which to develop over time. The AJP remains insufficient, however, to adequately address the political obstacles to government interventionism, make up for the long-term decline in US public investment, or to meet critical climate targets on its own.

Acquiring a Political Mandate: It's the Economy, Stupid

The Biden administration faces two key political challenges in enacting its broader developmentalist agenda: the first is a short-term requirement that it holds on to its majority in Congress, while the second is a medium-term project to restore faith in public institutions. The infrastructure package is not the sole mechanism for achieving these political ends, but it has to be understood in this context. As the director of Biden's National Economic Council and architect of the AJP, Brian Deese, put it in a recent interview: "your ability to sustain good policy is connected to your ability to sustain political support for that good policy".[7]

A key feature of Biden's plan to sustain political support is to avoid losing it. This sounds obvious, but the AJP is notable for the ideas it avoids, as much as the ones it embraces. In particular, it is constructed to avoid the type of backlash in 2022 that led to Obama's "shellacking" in 2010.[8] It is

[7] E. Klein, "The Best Explanation of Biden's Thinking I've Heard", *New York Times*, 9 April 2021.

[8] E. Patashnik, "Limiting Policy Backlash: Strategies for Taming Countercoalitions in an Era of Polarization", *The ANNALS of the American Academy of Political and*

instructive, for example, that the Biden administration has chosen to focus on green infrastructure spending and "jobs, jobs, jobs" in its climate provisions, ignoring calls for a carbon tax or other carbon pricing mechanism.[9] Officials have learned from the Obama's experience with cap-and-trade legislation in 2009, which created a populist backlash, spurred little positive support for climate action, and likely contributed to his mid-term defeat.[10] The Biden administration has so far managed to evade being dragged into these bitter climate debates, providing one less source of Republican turnout in the critical midterm election next year.

Nine of the last ten mid-term elections have swung against the party of the sitting president, and Biden will need to do more than avoid backlash. Instead, Democrats need to "go big".[11] While the cap-and-trade bill, Obamacare, and a Tea Party backlash may have hurt Obama's election results in 2010, the simplest explanation for the defeat was that the economy remained in terrible shape, with unemployment still nudging 10% as votes were cast.[12] In this respect, Biden has an advantage over his Democratic predecessor, with economic indicators suggesting a rapid post-pandemic recovery is already underway. Further, both Congress and the Fed appear to share Biden's view that the "[t]he risk isn't that we do too much … it's that we don't do enough".[13] The combination of trillions of

Social Science, vol. 685, no. 1, 10 September 2019, pp. 47-63.

[9] Y. Kempe, "Biden's climate mantra? 'Jobs, jobs, jobs'", *Grist*, 29 April 2021.

[10] T. Skocpol, "NAMING THE PROBLEM: What It Will Take to Counter Extremism and Engage Americans in the Fight against Global Warming", Symposium on The Politics of America's Fight Against Global Warming, January 2013.

[11] R. Brownstein, "Can Democrats Avoid a Wipeout in 2022?", *The Atlantic*, 29 April 2021.

[12] L. Bartels, "Political Effects of the Great Recession", *The ANNALS of the American Academy of Political and Social Science*, vol. 650, no. 1, 25 September 2013, pp. 47-76.

[13] J. Biden, [@POTUS], (10 February 2021). [Tweet]. Twitter. https://twitter.com/potus/status/1359655341944930309?lang=en

dollars in stimulus spending over 2020 and early 2021, and a loose monetary environment will likely see GDP growth and unemployment return to pre-crisis levels within Biden's first term, even without the accompanying Jobs and Families plans.[14]

The Biden administration is also ensuring that its policies are visible, as well as impactful. Where the short-term spending in Obama's American Recovery and Reinvest Act (ARRA) often took the form of hidden tax incentives or invisible "nudges" to consumer behavior, the American Rescue Plan loudly and proudly bore President Biden's name on US$400 billion worth of stimulus checks. Or as Obama himself noted recently: "you've got to sell the sizzle as well as the steak".[15] Further, unlike Obama's ARRA, which combined short-term stimulus and longer-term infrastructure spending, Biden has split his package into separate "rescue" and "recovery" components to ensure the effects of the former are immediately seen by voters. This also means he can afford to wait and negotiate the AJP through Congress, with enough short-term stimulus enacted already to keep the economy whirring through 2022.

This focus on both visibility and outcomes speaks to Biden's broader political goal: restore trust in American public institutions. The percentage of Americans who say they trust their government in Washington has been in free fall since 9/11.[16] The consecutive disasters of the Iraq War and Great Recession meant the proportion of Americans who "trust their government in Washington" had reached just 17% by 2011 and basically remained there until Covid-19 struck. An important explanation for this trend is the rise of the so-called "submerged

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[14] M. Zandi and B. Yaros Jr., "The Macroeconomic Consequences of the American Families Plan and the Build Back Better Agenda", *Moody's Analytics*, 3 May 2021.

[15] E. Klein, "Obama Explains How America Went from 'Yes We Can' to 'MAGA'," *New York Times*, 1 June 2021.

[16] Pew Research Center, *Public Trust in Government: 1958-2021*, Pew Research Center, 17 May 2021.

state".[17] Despite its growing overall size, government has become less visible in everyday life, causing the public to trust it less. In contrast to Reagan's famous "nine most terrifying words", the Biden administration is making an unapologetic case for big, visible government, which, according to early polling, is working, and officials will want to maintain that momentum through the AJP.[18]

Continuing this trend will require somehow avoiding political controversy and backlash, maintaining the economic expansion, and finding new ways to demonstrate where and how government is providing a helping hand. Any number of minor blunders could topple this delicate house of cards. For all the media will likely focus on political decisions, Biden's long-term project of establishing a mandate for a more expansive government will ultimately come down to economics. In particular, this administration's ability to create jobs and turn around the structural sources of political division and economic stagnation that have undermined political trust and economic activity for a generation.

Infrastructure and the "New View of Fiscal Policy"

The infrastructure package's success as a political project depends on the accuracy of what former chair of Obama's Council of Economic Advisors calls the "New View of Fiscal Policy".[19] Unlike the austerity economics that took hold in the years following the Great Recession, Biden's economic advisors are promoting an expansive role for government spending, as reflected in the AJP's US$2.3 trillion price tag.[20] In this

[17] S. Metler, *The Submerged State*, The University of Chicago Press, 2011.

[18] D. Cox, "Biden's Push For Big Government Solutions Is Popular Now - But It Could Backfire", *FiveThirtyEight*, 5 May 2021.

[19] J. Furman, "The New View of fiscal policy and its application", *VoxEU,* 2 November 2016.

[20] M. Blyth, *Austerity: The History of a Dangerous Idea*, Oxford University Press, 2015.

view, fiscal policy complements monetary policy, is relatively unrestricted by debt and deficit concerns, and is designed to increase long-term aggregate supply. These propositions were rediscovered the hard way. The period from 2009-2020 was defined by exceptionally weak wage, employment, investment, and productivity growth.[21] As a result, influential macroeconomists have changed their tune on the link between government spending and demand, and the importance of full employment to long-term economic growth.[22]

In addition to its focus on the additional benefits of fiscal policy, this new view places less emphasis on its risks. Fears that expansionary fiscal policy will result in runaway inflation have largely been put aside for the moment. Biden's economic advisors are notably less hawkish on inflation than even Obama's key staff, as seen in Larry Summers' repeated attacks on Biden's big spending agenda.[23] Even the Fed is switching gears, shifting to an average inflation targeting regime in 2020.[24] There are also fewer concerns about the sustainability of fiscal deficits, due to the low interest rate on government debt, higher expected spillovers of government spending, and a broader acceptance of high government debt in global capital markets. This can be seen in the Biden administration's first budget proposal, which includes forecasts of the "real net interest payment", predicting that the share of the budget going towards debt servicing costs will be negative relative to economic output until 2028, implicitly recommending that budget deficits should increase over that period.[25]

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[21] Center for Budget and Policy Priority, *Chart Book: Tracking the Post-Great Recession Economy*, CBPP, 4 June 2021.

[22] B. Delong, L. Summers, and L. Ball, *Fiscal Policy and Full Employment*, Center for Budget and Policy Priorities (CBPP), 2 April 2014.

[23] T. Pager and J. Stein, "Biden privately called Lawrence Summers, a critic of White House agenda, to discuss economy", *The Washington Post*, 3 June 2021.

[24] M. Boesler, "The Covid Trauma Has Changed Economics - Maybe Forever", *Bloomberg*, 1 June 2021.

[25] O. Blanchard, [@ojblanchard1], 29 May 2021, [Tweet], Twitter, https://twitter.com/ojblanchard1/status/1398563216809205760

Advisors will likely keep one eye on inflation but politically, the top priority is returning the economy to full employment. It is of course no coincidence that the Biden administration chose to brand their infrastructure package a *Jobs* plan. In a recent speech on the state of the economy, President Biden explicitly noted that full employment was the number one goal, not only because it means reduced unemployment, but as a way of increasing workers' bargaining power and wage growth.[26] He also noted how weak labor markets have led to long term challenges, such as rising political polarization, deaths of despair, atrophying skills in long-term unemployed, falling entrepreneurship and business dynamism, and declining productivity growth.[27] One of Biden's top economic advisors, Jared Bernstein, wrote an instructive report in 2018, which makes the case for government action in three ways: first, offset a demand contraction during economic downturns; second, create jobs directly through public works; and third, boost the supply-side of the economy, generating more labor market opportunities over the medium to long term.[28] All three roles are prominent in the American Jobs Plan.

First, at US$2.3 trillion, or around 10% of current GDP, the AJP alone provides about twice the counter-cyclical push as Obama's 2009 stimulus, though it is spread out over a slightly longer time period. According to Moodys Analytics, if Biden's three Build Back Better plans were to pass at a combined US$6.1 trillion, it would result in "a stronger economy over the coming decade, with higher GDP, more

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[26] J. Biden (2021).

[27] D. Autor, D. Dorn, G. Hanson and K. Majlesi, "Importing Political Polarization? The Electoral Consequences of Rising Trade Exposure", *American Economic Review*, vol. 110, no. 10, 2020, pp. 3139-3183; A. Deaton and A. Case, *Deaths of Despair and the Future of Capitalism*, Princeton University Press, 2020; M. Konzcal and M. Steinbaum, *Declining Entrepreneurship, Labor Mobility, and Business Dynamism: A Demand-Side Approach*, Roosevelt Institute, 21 July 2016.

[28] J. Bernstein, "The Importance of Strong Labor Demand", The Hamilton Project, 27 February 2018.

jobs and lower unemployment".[29] The Jobs Plan alone would increase economic growth by 1.6 percentage points, jobs by over 2 million employees, and return the economy to full employment by 2024. Importantly, this increase in aggregate demand can have an "accelerator effect" on private investment, increasing market activity as the prospects for new projects improve.[30] After the 2009 financial crisis, private investment experienced its weakest recovery from any recession in US history, and much will depend on the administration's ability to avoid a repeat of that scenario. There is evidence that austerity measures were partially to blame for this investment slump, particularly in Europe, suggesting the fiscal expansionism of a large infrastructure package could prompt a boom in job-creating investment.[31]

The plan also includes a series of direct job creation proposals and worker retraining programs, such as establishing a Dislocated Workers Program (US$40 billion), funding workforce development in underserved communities (US$12 billion), funding for construction-intensive infrastructure projects, and a US$10 billion Civilian Climate Corps (CCC). Such "active labor market policies" have been shown to increase employment and earnings outcomes, particularly for disadvantaged workers.[32] The US currently spends just 0.1% of its GDP on active labor market policies, such as retraining and job search services, compared to an OECD average of 0.52%.[33] The CCC is of course modelled on its New Deal predecessor,

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[29] M. Zandi and B. Yaros, "The Macroeconomic Consequences of the American Jobs Plan", *Moody's Analytics*, April 2021.

[30] J. Furman, *Business Investment in the United States: Facts, Explanations, Puzzles, and Policies*, Remarks at Progressive Policy Institute, 30 September 2015.

[31] C. House C. Proebsting and L. Tesar, *Austerity in the Aftermath of the Great Recession*, National Bureau of Economic Research (NBER), Working Paper 23147, February 2017.

[32] Council of Economic Advisors, "Active Labor Market Policies: Theory and Evidence for What Works", Obama White House CEA Issue Brief, December 2016.

[33] OECD, "Public expenditure and participant stocks on LMP," *OECD.Stat.*

whose enrollees "grew taller, lived longer lives and had higher lifetime earnings as a result of their participation".[34]

Finally, the Plan includes various provisions to augment potential growth in sectors like US manufacturing, clean energy and the care economy, where there is perceived to be ample room for medium-term employment growth and a high jobs multiplier on government spending.[35] This reflects the administration's broad definition of infrastructure, which, despite being politically controversial, adheres to the IMF's definition as "the basic structures that facilitate and support economic activity".[36] A recent paper from Biden's Council of Economic Advisors notes that "a strong economy depends on a solid foundation of public investment" that includes not just physical infrastructure, but investments in human capital, innovation and industrial policy.[37]

These are welcome developments, yet the policies outlined in the AJP remain insufficient in addressing the public investment needs that are at the heart of Biden's developmentalist ambitions. A commonly cited study by the American Society of Civil Engineers, for example, estimates more than US$2.5 trillion is required simply to maintain "B grade" quality infrastructure – almost US$2 trillion more than the AJP dedicates to physical infrastructure spending.[38] Further, while the AJP is large when compared to recent packages to make it through US Congress,

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[34] A. Aizer, S. Eli, A. Lleras-Muney and K. Lee, *Do Youth Employment Programs Work? Evidence from the New Deal*, National Bureau of Economic Research (NBER), Working Paper 27103, June 2020.

[35] R. Antonopoulos, K. Kim, T. Masterson, and A. Zacharias, *Investing in Care,* Levy Economics Institute Working Paper 610, August 2010.

[36] IMF, "Is it Time for an Infrastructure Push? The Macroeconomic Effects of Public Investment", in IMF World Economic Outlook: Legacies, Clouds, Uncertainties, October 2014.

[37] Council of Economic Advisors, "Building Back Better: The American Jobs Plan and the American Families Plan", Biden White House CEA Issue Brief, May 2021.

[38] ASCE, *2021 Report Card for America's Infrastructure*, Report Card for America's Infrastructure, 2021.

it would do little to arrest the long-term decline in American public investment. From its post-war highs of nearly 8% of GDP, government investment has been in free-fall, reaching its nadir of just 3.4% under the Trump administration.[39] At the peak of AJP expenditure, even if all spending were assumed to be counted as investment (almost certainly not the case), investment would only briefly tick over 5% of GDP in 2025. Yet each of Biden's intersectional goals of reindustrialization, racial equity, and decarbonization would likely require levels of public investment at least that high over the full course of his term.

Decarbonization as Infrastructure

The gap between this administration's goals and the contents of its plans is clearest in its approach to decarbonization. It is unclear yet whether the American Jobs Plan is Biden's climate plan, or its precursor. If it is the former, it is woefully insufficient. If it is the latter, it contains much that might facilitate future success in meeting his climate goals. New physical infrastructure will be needed to support massive deployments of renewable energy and electric vehicles; investments in innovation will help drive down the prices of these and other low-carbon technologies; industrial policy will help direct and, potentially, accelerate private investment; while human capital investments will ease the transition for workers and communities into a low-carbon economy. Few of the AJP's investments on their own will displace much carbon from the atmosphere, but as a catalyst for political, economic and technological change, they would represent a critical first step.

The physical infrastructure requirements of deep decarbonization are immense. About half of AJP spending goes towards climate-related activities, yet it remains well short of

[39] FRED, "Gross government investment (A782RC1Q027SBEA)", *FRED Economic Data.*

the investments needed to decarbonize the economy by 2050.[40] The US will need an additional 1000 GW each of transmission and distribution infrastructure to support the additional 3800 GW of new generation capacity – by contrast, the AJP includes a target of just 20 GW of high-voltage capacity power lines.[41] The US likely needs 50 million electric car charging stations to electrify a further 250 million cars and 5 million freight trucks – the AJP targets 500,000 charging stations. The appliances of nearly 100 million homes will all have to be electrified, as will the lighting, cooking, air conditioning and refrigeration units in 90 billion square feet of commercial real estate – the AJP plans to build or retrofit 2 million homes and commercial buildings. More than 8,000 industrial facilities will also need to decarbonize their production processes – the AJP includes few references, and no targets towards industrial decarbonization.

However, such comparisons do not tell the whole story. Direct funding of climate-related infrastructure is a small piece of the plan, and perhaps an even smaller share of its underlying developmentalist philosophy. In the short-term, the bulk of climate mitigation will be spurred by regulatory changes and demand-side incentives, while over a longer time-horizon, technological innovation and shifting investment patterns will be expected to do more of the leg work. In clean energy, for example, the AJP includes a provision for an Energy Efficiency and Clean Electricity Standard, which would incentivize producers to reach 100% clean electricity by 2035, as well as extending tax credits for zero-carbon electricity sources. In transport electrification, the US$174 billion set aside for electric vehicles includes demand-side consumer rebates and tax incentives for new sales. These measures would complement the growing list of executive actions and regulatory changes

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[40] L. Carey, M. Higman, and S. Naimoli, *The American Jobs Plan Gets Serious about Infrastructure and Climate Change*, Center for Strategic and International Studies (CSIS), 2 April 2021.

[41] S. Griffith and S. Calisch, "Mobilizing for a zero carbon America: Jobs, jobs, jobs, and more jobs", *Rewiring America*, July 2020.

made by the Biden White House, and likely displace far more carbon than the physical infrastructure build-out.[42]

This regulatory approach may be able to get some of the way towards Biden's aggressive climate goals, but where the developmentalist philosophy becomes readily apparent is the plan's faith in technological innovation and private investment mobilization. The extraordinary cost declines in solar, wind and lithium-ion battery technologies have engendered hopes that, with sufficient funding for research, development, and demonstration (RD&D), the necessary technologies in other sectors can also reach cost-parity with their carbon-intensive predecessors. The AJP includes US$35 billion for climate-related R&D, and a further US$15 billion for demonstration projects. This would increase annual energy RD&D from about US$8 billion annually to an average of about US$14 billion, a significant increase but still short of the tripling in funding recommended by the National Academies of Sciences and others.[43] The plan also includes a provision to establish a new Advanced Research Projects Agency-Climate, to address so-called "valley of death" issues in technology innovation. Such structural changes to America's innovation ecosystem are overdue. However, as seen in negotiations over the *Endless Frontiers Act*, there is no guarantee Congress won't water down such ideas until they're barely recognizable.[44]

Much as the AJP aims to catalyze the private development of new technologies through early-stage government funding, the plan also relies on mobilizing significant flows of private capital into clean energy sectors. Though estimates vary, studies have

[42] Sabin Center for Climate Change Law, *Climate Reregulation Tracker*, Columbia Law School.

[43] National Academies of Sciences, Engineering, Medicine, *Accelerating Decarbonization of the U.S. Energy System*, National Academies Press, 2021; C. Cunliff and L. Nguyen, "Energizing Innovation: Raising the Ambition for Federal Energy RD&D in Fiscal Year 2022", *Information Technology & Innovation Foundation*, 17 May 2021.

[44] S. Hammond, "How Congress Ruined the Endless Frontier Act", *Niskanen Center*, 20 May 2021.

put the total capital requirements for decarbonization at well over US$1 trillion annually, and double that by 2040.[45] Where Green New Deal advocates argue that the federal government should step in directly to fill the gap between existing capital and these needs – see the THRIVE agenda's US$10 trillion price tag – Biden's developmentalist instincts point towards more of a hybrid solution.[46] It is not yet clear which approach is more likely to be successful. On the one hand, direct public investment guarantees targets would be met, but is likely to provoke political backlash to Solyndra-style controversies. On the other, the developmentalist model takes advantage of enormous pools of global capital, but relies on private financial markets to shift toward a longer-term, greener investment model that has no precedent or guarantee.

The developmentalist preference for public-private cooperation is clear in the plan's reliance on tax incentives and new public financial institutions. In high voltage transmission lines, renewable electricity generation, EV charging, hydrogen demonstration projects, clean energy manufacturing, and carbon capture and storage projects, expanded or consolidated tax credits appear to do the bulk of the financing work in Biden's infrastructure plan.[47] While there is some shift towards direct financing in the plan through a cash refund of the tax credit, this remains a long way from the sort of public investment role that characterized New Deal projects like the Tennessee Valley Authority. This can also be seen in the Clean Energy & Sustainability Accelerator, which more or less resembles the sort of "Green Bank" that has become an increasingly popular hallmark of the developmentalist approach to climate policy worldwide.[48] According to an influential industry group

[45] E. Larson et al., *Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report*, Princeton University, 2020.

[46] "THRIVE Agenda", *Green New Deal Network*, 2020.

[47] K. Aranoff, "Why Biden's Infrastructure Plan Shouldn't Use Tax Credits to Encourage Clean Energy", *The New Republic*, 20 May 2021.

[48] A. Whitney, T. Grbusic, J. Meisel, A. Becerra Cid, D. Sims and P. Bodnar, *State*

supporting the proposal, with a US$100 billion capitalization, the Accelerator would create US$463 billion in private investment over four years, "crowding in" the private sector to fill the gaps left unaddressed by the AJP.[49]

Finally, the AJP is an investment in the practical implications of "green jobs". Namely, ensuring there are enough trained workers living in the right areas of the country. Just as importantly, avoiding political backlash and economic hardship for those left behind in the carbon-intensive industries of the past. The AJP includes several provisions for worker training and skills enhancement, as discussed above, but the real shift is towards the adoption of so-called "place-based" policies.[50] In this, the Biden administration recognizes that the variety and quality of jobs varies dramatically by region across the country, requiring policies tailored to specific geographic conditions. This is particularly relevant for climate policy, since the geographic distribution of fossil fuels (and therefore, fossil fuel-related jobs) in the country is uncorrelated with that of renewable energy potential (and green jobs). As such, the AJP includes various "Just Transition" policies that aim to minimize the burden of the clean energy transition on fossil fuel communities through climate-related job creation.[51] This includes US$16 billion to plug orphaned or abandoned oil and gas wells, for example, and provisions for the benefits of various tax credits to be concentrated in former coal mining regions. While the philosophical shift to place-based policymaking is an important development, there is little evidence that the provisions currently included in the AJP would do much to reverse decades of growing geographic inequality and deindustrialization.

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of Green Banks 2020, Rocky Mountain Institute, 2020.

[49] Coalition for Green Capital, "Bipartisan Legislation for a Clean Energy & Sustainability Accelerator: $100B Seed Capital to Create Jobs and Build Clean Energy Infrastructure for an Equitable & Just Transition", *Coalition for Green Capital*, 11 February 2021.

[50] R. Nunn, J. Parsons and J. Shambaugh, *The geography of prosperity, Place-Based Policies for Shared Economic Growth*, Hamilton Project, 2018, pp. 11-42.

[51] CSIS & CIF, *Just Transition Initiative,* 2020.

Conclusion

The American Jobs Plan manages to be both ambitious and pragmatic, visionary and incrementalist, necessary and insufficient. Its developmentalist approach is surely the most promising path forward politically and economically in reaching mid-century climate goals. However, the overwhelming obstacles to such a vision require small steps, gradual changes, and more than a little bit of luck along the way. What's more, it is unlikely that any of its political, economic or decarbonization goals will succeed without the other. Massive government intervention for the sake of a clean energy transition will require a large political mandate; political success relies on a strong economy; and economic prosperity is increasingly reliant on the promises of green growth and technological innovation. This increases the difficulty of execution exponentially. Yet it may also generate its own self-sustaining momentum, as one success begets another. A hot economy creates the conditions for a political upset, allowing policies that further improve economic conditions and the state's capacity to deliver a zero-carbon economy. The American Jobs Plan is our first indication that the Biden administration might just be able to pull off such a magic trick. With a little luck, and savvy Congressional negotiation, it might just be able to return developmentalism to the annals of US history, and secure its President his wish to sit prominently within its pages.

10. China and the Energy Transition: The Bumpy Road Ahead

Michal Meidan

What Is Behind China's 2060 Carbon Neutrality Pledge?

On 22 September 2020, Chinese President Xi Jinping announced at the UN General Assembly (UNGA) that China would aim to peak its carbon dioxide (CO_2) emissions before 2030 and reach carbon neutrality by 2060. Under the Paris Agreement's nationally determined contribution (NDC), China had committed to peaking CO_2 emissions by 2030 – without, however, issuing a level at which emissions would peak – and was widely expected to reach this goal before 2030. Thus, the ambition to peak emission at an unspecified time before 2030 does not represent a large shift from China's previous commitments. However, reaching carbon neutrality by 2060 represents a significant change with wide implications locally and globally. From a domestic perspective, China will have to scale up renewables dramatically while investments in the power sector and the technologies underpinning the energy transition are set to boost China's economy.[1] Internationally, the unilateral pledge is hugely important in generating global

[1] H. Pollitt, "Analysis: Going carbon neutral by 2060 'will make China richer'", *Carbon Brief*, 24 September 2020.

momentum toward stronger global climate ambition and governance as well as in positioning China as a leader in climate diplomacy.

Yet the challenges are equally tremendous. As the world's largest emitter of greenhouse gas emissions – with an energy system heavily reliant on coal – reaching carbon neutrality would require a fundamental change in China's energy supply systems and in the way energy is consumed. Put simply, China would need to reverse its energy mix: from currently relying on fossil fuels for 85% of its energy mix to having non fossil fuels account for 85% of energy use by 2060. This, in turn, implies a profound transformation in China's economic structure and a shake-up of the fossil fuels industry, a politically powerful lobby. Indeed, when considering China's renewed focus on energy security and the large number of coal-fired power plant approvals over the past year,[2] Xi's pledge came as a surprise to many observers within and outside China. Nonetheless, when considering that China has historically met or exceeded its international climate commitments, there is no reason to assume that the 2060 carbon neutrality goal is an empty pledge. While there are few details on how China aims to achieve carbon neutrality by 2060, with further clarification likely to be included in China's updated NDC ahead of the Glasgow climate conference in November 2021, Xi's pledge should be seen as the beginning of a policy planning process rather than the culmination of one.

Why now?

China's leaders have long recognised that rising sea levels could affect more than half a billion people living in coastal areas, including major cities like Shanghai and Guangzhou. More extreme weather, such as droughts, would lead to food

[2] P. Andrews-Speed, S. Zhang, and C. Wang, "Does 2020 mark a critical juncture in China's low-carbon energy transition?", *Oxford Energy Insight*, no. 76, October 2020.

shortages, and higher temperatures would accelerate the melting of glaciers on the Tibetan Plateau, increasing the flood burden in densely populated areas. The extreme weather events in 2020 were a warning shot of what lies ahead.[3] Moreover, China has long sought to electrify the vehicle fleet due to energy security concerns, namely a desire to reduce dependency on imported oil, as well as the industrial opportunity presented by developing new supply chains.

In 2020, however, the urgency to implement these goals at an accelerated pace grew in light of China's worsening external environment, highlighted by concerns about China's centrality in supply chains in the wake of the Covid-19 pandemic and after years of trade tensions with the US. The energy transition lies at the intersection of these priorities: China's renewed focus on energy security, technological self-reliance and the resilience and reliability of supply chains[4] means that developing the technologies and ecosystems that enable the energy transition could bolster the country's leadership in a global economy that is increasingly climate- and environment-conscious. Already in 2019, Chinese manufacturers supplied 42% of the world's wind turbines and 76% of the world's solar modules. Going forward, Chinese ministries have estimated[5] that achieving carbon neutrality by 2060 could yield over 100 trillion yuan (US$14.7 trillion) in investments over the next 30 years, or 1.5-2.0% of China's GDP over the period. Other estimates suggest the net zero ambition could boost China's GDP by 5% through 2030.[6]

Taking a leading role in the global economy through low-carbon, high-tech, and information technologies is a direct

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[3] "China floods: 100,000 evacuated, Leshan Buddha threatened".

[4] M. Meidan, "COVID-19 and the electrification of the Chinese economy", *Oxford Energy Comment*, The Oxford Institute for Energy Studies, June 2020.

[5] "He Jiankun: To achieve carbon neutrality, we must increase efforts in several directions" (Chinese), *Yicai*, 29 September 2020.

[6] "China's net zero ambition could boost GDP by 5% during this decade", *Cambridge Econometrics*, 24 September 2020.

continuation of China's industrial policies: the much-criticised Made in China 2025 policy, the more recent High Quality Development model[7] and New Infrastructure Plan highlight these priorities. Going forward, China's 2035 vision and its China Standards 2035 papers will further stress that China is seeking a role in higher margin industrial manufacturing and increasingly in standard setting too.[8] At the same time, failure to adjust to the energy transition could prove costly for the Chinese economy when considering growing calls for carbon tariffs or carbon border adjustment mechanisms.[9]

Xi Jinping's carbon neutrality pledge was therefore likely informed by a number of factors, including the assessment that the country is facing an increasingly challenging international environment and must therefore ensure that its industrial and manufacturing capabilities are fit for purpose in an increasingly carbon-conscious world.

But what does it mean for China's energy system?

The metrics and the pathway to reaching carbon neutrality by 2060 are still vague. It remains unclear whether the target covers only CO_2 or all greenhouse gases (GHGs). Energy sector emissions would likely need to fall faster and deeper if GHG emissions are included, although they are not expected to be. At the same time, different assumptions about which emissions are included in the pledge and how much CO_2 can be taken up by ecosystems, or removed using negative emissions technologies,

[7] "China has entered a stage of high quality development" (Chinese), *Xinhua*, 8 August 2020.

[8] T.N. Rühlig, *Technical standardisation, China and the future international order: A European perspective*, Henrich Boll Stiftung e-paper, February 2020.

[9] Yujing Niu, Wenying Chen, and Zongxin Wu, "The economic and environmental impact on China of carbon tariffs based on GAGE model", *Energy & Environment*, special double issue: "Energy, Climate and Environmental Policy in China", vol. 24, no. 7/8, 2013, pp. 1295-1307; Weiguang Chen and Qing Guo, "Weiguang Chen and Qing Guo, "Assessing the Effect of Carbon Tariffs on International Trade and Emission Reduction of China's Industrial Products under the Background of Global Climate Governance", *Sustainability*, 15 June 2017.

lead to widely varying budgets for energy-sector emissions. Optimistic assumptions about CO_2 removal from afforestation would leave more space for residual fossil-fuel emissions.

China's prestigious Tsinghua University's Institute for Climate Change and Sustainable Development (ICCSD) – which reportedly informed Xi Jinping's announcement – presented a number of scenarios suggesting potential pathways China could adopt. These scenarios indicate that the electricity sector would need to get to zero emissions by 2050 and start delivering "negative emissions" thereafter, coming from bioenergy with carbon capture and storage, in order to offset hard-to-eliminate emissions from industrial processes, agriculture and other sectors.

Power generation from coal without carbon capture and storage (CCS) should therefore be phased out by roughly 2050, even though some coal could still be used outside the power sector until 2060. In the ICCSD scenarios, the share of coal in the overall energy mix already falls below 5% in 2050 and well below 10% in the power sector. This would mean closing down all but a few of the 3,000 coal-fired power units and 5,000 coal mines operating in China today. Since the main strategy for phasing out fossil fuels outside of the power sector is electrification, emissions-free power generation will need to replace not only China's coal-fired power plants – which today account for roughly half of the world's total – but also much of the coal and oil consumption in industry, transport and heating sectors. Reaching these targets means growing China's solar power capacity by about tenfold and wind and nuclear power capacity sevenfold by 2050.

At the same time, total energy consumption would need to peak by 2035, after which the growth in clean energy would go entirely towards displacing existing fossil fuel use. This would be in contrast with the dynamic so far, with emissions increasing in spite of the increasing share of clean energy, due to rapid growth in overall energy demand.[10]

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[10] "Influential academics reveal how China can achieve its 'carbon neutrality'

Does the 14th Five Year Plan Reflect China's Climate Ambitions?

But China's 14th Five Year Plan, released in March 2021, which was expected to showcase China's climate ambition, seems to fall short of expectations. The "Outline for the 14th Five Year Plan and long-term targets for 2035",[11] is a general framework outlining a number of binding and aspirational targets. Forthcoming plans related to energy, climate and industrial development, as well as provincial plans, will offer additional details and more specific targets. So when assessing the Plan, it is important to keep in mind that both the central and local governments seek to ensure that binding targets are reachable, and at times may frame their goals in a way that seems to lack in ambition. The Plan, therefore, seeks to balance ambition and political reality and must also incorporate a number of policy priorities which at times can be contradictory[12]. To an extent then, the Plan was short on ambition and big on political reality. The plan states that the country will boost the share of non-fossil sources in its energy mix (including nuclear and hydropower) to "around 20%" by the end of the period, from a targeted 15% by 2020 (and 15.8% achieved). Not only is the 20% target not binding, but it is also a rather small acceleration of existing trends, given that over the course of the 13th FYP, the share of non-fossil fuels increased by 3.6 percentage points and is now expected to increase by 4.2 percentage points.

Second, the Plan contains multiple references to the development of coal, even though it emphasises "clean and efficient utilisation", largely related to the need to ensure energy security in the face of an increasingly hostile external

goal", *Carbon Brief*, 14 October 2020.

[11] In Chinese http://www.xinhuanet.com/politics/2021-03/11/c_1127200766.htm

[12] P. Andrews-Speed, Y. Qin, and M. Meidan, "Key issues for China's 14th Five Year Plan", *Oxford Energy Comment*, The Oxford Institute for Energy Studies, March 2021.

environment. It is notable that in this FYP, the government issued a binding floor for domestic energy production, looking to maintain domestic supplies (of all energy sources) at above 4.6 billion tonnes of standard coal equivalent (tsce). In 2019, China consumed 4.86 billion tsce of energy, and China National Petroleum Corporation (CNPC), for example, forecasts primary energy demand will reach 5.6 billion tce by 2035[13]. So the government is clearly looking to maintain as much self-sufficiency in its energy supplies as possible. In this vein, China did not include a coal consumption cap, although one may still be issued in upcoming sectoral plans. So, even though renewables will clearly be encouraged, the Plan does not include targets for installed capacity by 2025 nor does it reiterate Xi Jinping's announcement that by 2030 China will install 1,200 GW of wind and solar capacity.[14] These, however, are likely to be stated in forthcoming plans.

Third, the Plan does not include a carbon emissions cap, stating only that carbon intensity controls will be "supplemented" by controls on total emissions. This confusing wording suggests that while the government is looking to control and reduce emissions, it remains concerned about the impact of the pandemic on economic growth and is therefore avoiding issuing emissions quotas in a top-down manner. Indeed, a top-down approach could also face local resistance.[15] Moreover, mandatory top-down instructions have backfired in the past, when local officials needed to reach targets and resorted to cutting off power supplies, as was the case in Zhejiang province in the winter of 2020.

In addition to the politics of the planning process, the reality of China's expected economic growth and related rise in energy use suggests that it will be hard to phase out existing energy

[13] China National Petroleum Corporation (CNPC), *2050 Energy Outlook*, 2020.

[14] "China aims to push wind and solar capacity beyond 1,200 GW by 2030", *Reuters*, 12 December 2020.

[15] "Q&A: What does China's 14th 'five year plan' mean for climate change?", *Carbon Brief*, 12 March 2021.

supplies, even as the country focuses on adding green supplies. The transition will take time, especially considering that China's economic structure is still highly energy intensive: its emissions per unit of GDP are among the highest in the world (about 1 metric ton of carbon dioxide equivalent for each US$1,000 of GDP in 2019, or roughly double the global average). China's heavy industries, such as steel and cement manufacturing, account for about 50% of global production and for 17% of its total carbon emissions.

While China has achieved cutting-edge energy efficiency in some industries, it lags behind developed countries in many others. For example, it consumes almost 30% more energy per ton of cement produced than some developed countries because of the lower scale of production, frequent stoppages caused by overcapacity, and low manufacturing efficiency. Finally, although economic growth is slowing, urbanisation continues. Already, China's urban residential areas are about 1.5 times larger than they were a decade ago, and annual passenger car sales are almost twice as high. Urban construction and transportation have continued to fuel both demand for energy and carbon emissions.

But green infrastructure and industries will receive a boost

Yet the hope in Beijing is that if structured well, China's new growth pathway will lead to accelerated innovations and development in a number of emerging industries, which should allow China to solidify its position as a leader in the science and technologies of the twenty-first century. Already between 2010 and 2019, China attracted US$818 billion of investment in the renewable sector, making it the world's largest market for both solar PV and solar thermal energy. 38% of all global renewable energy jobs are in China, which are estimated to have reached 4.4 million jobs in 2019. China's progress toward carbon neutrality is expected to create further job opportunities across a host of industries including battery production, renewable energy, construction (such as retrofitting existing buildings), and related services including shared mobility.

The carbon neutrality goal is also intended to facilitate China's industrial structural reform as it shifts away from polluting, carbon-intensive industries to low-carbon industries. The low-carbon transition will increase industrial total factor productivity, change production methods, and cultivate new business models, therefore helping to achieve China's goal of structural adjustment, optimisation and upgrade.[16]

For instance, given that fossil fuels will remain part of the energy mix for the foreseeable futures, China will need to reduce emissions using such removal measures as carbon capture and storage (CCS) and carbon sinks. China is no newcomer to CCS, with various demonstration projects and support schemes introduced over the past two decades, but their scale is small, heavily concentrated in coal-fired power plants or in enhanced oil recovery, with a collective capturing ability of less than 0.01% of China's current total carbon emissions.

The 2060 carbon neutrality pledge will likely bolster new CCS and CCUS (carbon capture, utilisation and storage) technologies. Given the pressure on heavy industries to begin decarbonising during the 14th FYP period (2021-25), and preparations for their inclusion in the national emission trading market over the next few years, efforts to scale up CCS and CCUS are increasing. Already, a number of projects are being considered in iron and steel as well as cement. But much will depend on financial incentives and subsidy schemes (or penalties imposed by the emissions trading scheme or other mechanisms). China's National Development and Reform Commission (NDRC) has stated it will issue policies to support low-carbon technology like CCS, hydrogen and utility-scale energy storage.

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[16] Baiping Chen, L. Fæste, R. Jacobsen, M. Teck Kong, D. Lu, and T. Palme, "How China Can Achieve Carbon Neutrality by 2060", BCG, 14 December 2020.

Furthermore, as investment in hydrogen increases in China – given that most of China's hydrogen is grey or blue – it will likely be coupled with CCS/CCUS technology to begin with. Indeed, China is no newcomer to hydrogen development. In fact, the country's hydrogen production was estimated at 22 million tonnes (Mt) by the China Hydrogen Alliance in 2019, making it the world's largest producer. But unlike many other countries where steam methane reforming (SMR) is the dominant production route, in China coal remains the most common feedstock for hydrogen. Policies to develop hydrogen date back to the 10th Five Year Plan (2001-05) with a focus on the transport sector.[17] In light of China's efforts to develop its technological capabilities and remain a leading supplier of global clean-tech, hydrogen will be key in China's path to carbon neutrality. Indeed, hydrogen was listed in the 14th FYP under the emerging industries that decision makers see as a priority. Given that these designations lead to state-support in the form of capital and human resources, the focus on hydrogen bodes well for its development. Moreover, with an expected increase in renewables, water electrolysis powered by electricity sourced from renewables is likely to become the major source of China's hydrogen supply. But China currently lacks the key technologies to enable renewables-based hydrogen production, and lags behind advanced economics in hydrogen storage and transport technologies as well as in manufacturing capacity for key materials. Even though China's 14th FYP stresses technological self-sufficiency and efforts to develop breakthrough technologies such as hydrogen, this could take time.

Many other initiatives, including green transportation, for instance, build on existing policy priorities. In 2019, China's Ministry of Transport, in conjunction with 12 other ministries, issued a Green Travel Action Plan for 2019-22. The plan includes efforts to expand China's high-speed trains, the

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[17] See M. Meidan, "China's emerging hydrogen strategy and the 2060 net zero commitment", in *The Role of Hydrogen in the Energy Transition – forum*, Issue 127, May 2021.

construction of subway systems as well as the development and deployment of electric buses. The government's focus on reaching carbon neutrality by 2060 suggests these plans will be accelerated and more funding devoted to the deployment of green transport. But in order to advance China's 2060 goals, investments in electrification will need to go hand in hand with decarbonisation.

The Geopolitical Implications of China's Energy Transition

While there are a number of potential pathways toward reaching carbon neutrality in China, the end result is clear: lower consumption of coal, oil and gas – and therefore reduced imports over time – and growing energy independence as renewable sources are produced locally. But even as China external dependence on fossil fuel starts to wane over the coming decades, its need for other critical materials and minerals such as lithium, nickel, cobalt, manganese and graphite will rise. China's diplomatic efforts will therefore continue to seek a stable environment for resource extraction and trading, albeit with a new set of countries and with different trading environments and networks than those governing oil, gas and coal trading. It is highly unlikely that China's energy transition will lead to a more inward focused diplomatic profile.

On the contrary, China's first-mover advantage in some of these supply chains and in mineral extraction means that Chinese companies will be at the forefront of setting standards across these value chains and if currency internationalisation proceeds, China's national currency, the Renminbi, could underpin some of these traded markets. But competition for technological dominance between China, the US and the EU, as well as rising concerns about China's commercial practices, suggest that the supply chains that exist today will be fraught with tensions and dislocations and that new supply chains will become the new focal points of geopolitical competition.

11. Japan's Sustainable Strategy: The Path Towards Carbon Neutrality

Corrado Molteni

On 26 October 2020, Japan's Prime Minister Yoshihide Suga announced during his first major policy speech in the Diet that by the year 2050 his country will achieve carbon neutrality. Later, at the end of December, the government released a tentative roadmap, the "green growth strategy" (*guriin seichō senryaku*), framed around the following goals: 1) full shift to electric vehicles by the mid-2030s; 2) development of an extensive network of wind power plant within 2040; 3) increase of the share of power generation from renewable sources from the current 18% to 50-60% of the total supply by the year 2050. This is still a conservative and cautious approach, if compared with the bolder plans announced by other industrialised countries such as Germany, which is expected to produce about 80% of its electricity from renewable resources by the same year, 2050. Yet the new strategy is going to affect profoundly the future of the country, the reorganisation of its industrial structure and its role and position in the global market. This will be even more evident this summer when a detailed plan with more specific targets will be announced as part of the ongoing review of the Basic Energy Plan (*enerugii kihon keikaku*) adopted in 2018.

In Japan, the announcement has sparked a lively debate, drawing considerable attention from the media and industrial circles. Although there is a widely shared consensus on the need to attain the goal, there is still uncertainty on how to proceed, and concern about the economic and social costs it entails. For example, the car industry is deeply concerned about whether or not cars using hybrid propulsion will be considered electric vehicles. Having invested heavily in this innovative technology, Japanese companies fear an economic backlash if hybrid cars were to be excluded from the domestic and international markets. And these concerns explain why the association of automobile manufacturers JAMA has recently launched a major advertising campaign reminding the public, politicians and bureaucrats in the relevant ministries of the importance of this industrial sector for the Japanese economy.

Ultimately, the success or failure of the new strategy will depend both on the capacity to develop and use new and competitive green technologies and on the future of the existing but idle nuclear reactors, potentially a major source of clean energy. Currently, the utilisation of nuclear power is still hampered by the negative impact of the Fukushima debacle and the unresolved issue of how to dispose of nuclear waste in an earthquake-prone country like Japan. Yet many in the government and industry believe that Japan should continue to rely on nuclear power. Slowly but steadily, this opinion seems to be gaining ground, but the options are still open, and a clear, binding decision has not yet been taken.

A Brief Overview of Japan's Energy Policy since 2011

Japan's energy policy was totally derailed in the spring of 2011, when a magnitude 9.0 earthquake and a massive tsunami struck the coast of north-eastern Japan. In the early afternoon of 11 March, the six nuclear reactors operating at the Fukushima Daiichi Power Plant were submerged by huge waves that knocked out all the emergency systems and caused the dramatic meltdown of the core components of the reactors. The human and economic impact of this major disaster was enormous, with the displacement of thousands of individuals from their homes and the shutdown of all of Japan's 54 nuclear reactors, forcing the government to impose severe restrictions on electricity consumption.

At that time, nuclear power accounted for more than one quarter of all electricity generated in the country and the policy, approved by the Democratic Party administration just one year earlier, in 2010, aimed to further increase that share to 40% as part of the 3rd Basic Energy Plan. Then, in the aftermath of the Fukushima nuclear accident, the government reversed its stance and decided to phase out the nuclear power industry by 2030 with the adoption of a new strategy, lacking details and vaguely defined as the "Innovative Energy and Environment Strategy".

However, things changed again in 2012, with the return to the helm of the country of the Liberal Democratic Party led by Shinzo Abe. In view of the significant economic losses arising from a rapid and complete nuclear phase-out, but also as a result of the considerable political influence exerted by the industry and its supporters in the ruling party and the bureaucracy, a powerful network known in Japan as the "nuclear village" (*genpatsu mura*), the Abe government announced a second policy reversal. In 2014, with the adoption of the 4th Basic Energy Plan, it was decided to gradually restart nuclear power generation, with the aim of supplying 20-22% of the country's electricity mix by 2030. This was confirmed in the Long-Term Energy Outlook of 2015. Yet the goal is far from being achieved. Due to the opposition of local governments, the still negative attitude of public opinion toward nuclear energy and the rulings by district courts against restarting nuclear power plants, out of 33 existing and potentially viable reactors only 9 are active today, and in 2019 they provided only 6% of the energy supply. And the prospects for the resumption of operations of the still idle nuclear plants remain grim.

The bleak picture is aggravated by the fact that Japan is lagging far behind other nations in the development of alternative energy sources. According to data provided by the Ministry of Economy, Trade and Industry (METI), in fiscal year 2019, renewable energy sources accounted for only 18% of the electricity mix. Of this, 6.7% was generated from photovoltaic installations, 7.7% from hydropower, 2.6% from biomass, 2.3% from geothermal sources and only 0.7% from wind power.

As a result, fossil fuels continue to play a key role. In fact, 37.1% of the electricity mix is provided by power plants using liquified natural gas (LNG) imported from overseas, while 31.9% is generated by coal-fired plants. The latter has actually increased its share over the last decade as coal has replaced nuclear power as a major source of energy, with newly constructed coal-fired plants and others in the process of being completed. In this respect, Japan's energy policy has moved in the opposite direction to that of all other industrialised countries, which have gradually or, as in the case of the UK, drastically reduced their dependency on coal. Japan's increased reliance on coal-fired plants has hampered the country's efforts to rein in CO_2 emissions and resulted in the embarrassing conferment by environmental groups of the "Fossil of the Day" award at the COP25 in 2019.

Toward a Carbon-Neutral Industry Structure: The Issues Ahead

The Japanese government's decision to achieve decarbonisation by 2050 came in the wake of similar announcements by competitors and allies. Besides the EU presentation in December 2019 of the European Green Deal aimed at climate neutrality by 2050, the Japanese government was certainly driven into action by the Chinese decision to achieve carbon neutrality by 2060. This was announced with great fanfare on 22 September 2020 – just one month before Suga's speech – by Chairman Xi Jinping at the General Assembly of the United Nations. Moreover, as pointed out by Japanese scholars and commentators, it was important for the Japanese government to assume a clear stance before the US presidential election. It would in fact have been quite embarrassing to announce the new policy goals after Biden's election, and would have been even more problematic in the case of victory by the incumbent US President.

The government decision has been welcomed by Mr. Hiroaki Nakanishi, Executive Chairman of Hitachi and Chairman of Keidanren, the powerful association representing Japan's big business. He approved what he called a "wise decision" and expressed his support for the restructuring of the power industry, a particularly important endorsement as Hitachi is a key player in the energy sector. A similar stance was adopted by JERA, Japan's main power generator and a vocal supporter of offshore wind power projects and the use of ammonia and hydrogen for thermal power generation. And in recent months many companies have been launching new projects aimed at promoting decarbonisation. Utilities like Tokyo Gas have announced large investments in offshore wind projects, while Toshiba is planning to develop and manufacture the turbines, a market currently dominated by European and Chinese makers. Carbon dioxide recovery and recycling is another technology in which Japanese companies are eager to invest.

According to the Japanese government's vision, to achieve carbon neutrality by 2050, renewable resources are expected to account by then for 50-60% of the electricity mix, the use of hydrogen and ammonia for 10%, while the remaining 30 to 40% would be supplied by nuclear power and thermal power utilising the new technologies to capture, utilise and store CO_2. To this end, the government is expected to provide guidance and support, but the financial burden will rest mainly on the private sector. Given the fiscal constraints and the large and growing public debt, government funding will be limited. To promote innovation, research and investment in green technologies, the government has set up the Green Innovation Fund (*guriin inobeeshon kikin*), but with an allocation of a mere 2 trillion yen, it is a tiny fraction of what the US and the EU plan to invest for the green economy. Even South Korea is planning to invest more than Japan, with the equivalent of 7 trillion yen earmarked for investment in green technologies over five years.

The resources of the government fund are indeed quite limited but could be the seed money that triggers a surge in privately financed loans and investment, as has happened in the past, although such an outcome cannot be taken for granted today as Japanese financial institutions are now less prone to follow unconditionally the government line. The government should also listen to economists and experts and promote more decisive deregulation to foster competition and remove existing barriers. For example, grid access is currently granted on a first-come-first-served basis, a policy that favours major companies and reduces the incentives for new players to invest in the sector. As a result of this and other constraints, 80% of power generation and retail is still provided by powerful incumbent corporations, benefitting from the advantages acquired in the past when the market was dominated by 9 regional entities operating within a monopolistic structure.

New Technologies: Hydrogen and Ammonia

To achieve decarbonisation as scheduled, the government and the private sectors have high expectations for hydrogen and ammonia as power sources. Yet in both cases, there are still many obstacles to overcome.

In the case of hydrogen, it is expected to be employed in power generation, transport equipment and steel production, and is already used in vehicles with fuel cell engines. Major companies like Toyota and Honda have already invested heavily in this new technology and have developed cars that are currently manufactured and marketed in Japan, albeit at an exorbitant price well beyond the reach even of wealthy individuals.

The growth of the fuel cell vehicle market is also hampered by other factors. Firstly, by the price of hydrogen itself. According to Nikkei Business, the Japanese government expects a sharp reduction in prices with the increase of domestic demand, currently at 10,000 tons per year but estimated to reach 3 million tons in 2030 and 200 million tons in 2050. As a result, the price of hydrogen is expected to drop to 30 yen per normal cubic meter (Nm^3) by 2030 and to less than 20 yen by 2050. However, the current price at the few gas stations operating in the country is still around 100 yen per Nm^3, a price kept below cost to stimulate consumption. To overcome this bottleneck, in December last year, 88 corporations, including Toyota, Mitsui-Sumitomo Financial Group and Iwatani Sangyo, the company constructing and managing the gas stations, joined forces to accelerate the expansion of the distribution network. This is indeed a clear sign that companies are cooperating in their attempts to create and develop the market.

A second constraint is the emission of CO_2 at the hydrogen production stage. Hydrogen is currently obtained from natural gas and, in the process, large quantities of carbon dioxide are produced. There are already attempts to produce it from lignite, available in large quantities in Australia, but the outcome is still uncertain. Other possible solutions are currently being considered, including the capture and storage of CO_2 in the soil, a project discussed with the Australian government, but its availability for commercial purposes is not yet in sight. In the end, the solution might be the production of green hydrogen by using renewable energy sources. To this end, NEDO, the national agency for research in the field of energy and industrial technology, is running one of the world's largest facilities for hydrogen production with photovoltaic generated electricity in the prefecture of Fukushima. However, the use of this and other renewables for hydrogen production is still hampered by its high cost.

Finally, a third obstacle is the cost and technical problems of transport. Hydrogen in fact has to be transported in liquified form and must be kept at a temperature of -253°C. Kawasaki Heavy Industry has already built a ship for this purpose and will soon start operating it. However, to satisfy the potential demand, a whole fleet would need to be constructed and launched.

Similar problems and constraints affect the use of ammonia. In principle, by mixing ammonia with coal in thermal plants the level of CO_2 emissions can be reduced, but once again the problem lies in the gas production process, since the currently used technologies involve the release into the atmosphere of large quantities of carbon dioxide. As in the case of hydrogen, it requires the adoption of efficient and cost-effective methods, and ultimately relies on the development of competitive technologies involving the use of renewable energy.

Conclusion

On 15 December 2020, the Council for Government-Industry Dialogue for offshore wind in Japan released its "Vision" for the industry, a blueprint for the development of this industrial sector. In Japan, Visions are documents outlining the strategy and the path to be followed in developing a specific industrial sector. They are not binding but do provide a roadmap for stakeholders in the public and private sectors. They are normally drafted by government committees steered by the key ministry or ministries in charge and with the participation of representatives of industrial associations, private firms and academia. The members of the Council for offshore wind power are officials from METI and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), managers of power companies and manufacturers, and representatives of the construction industry. The stated goal of its "Vision" is to develop a capacity of 45 million kW by 2040. A remarkable feat, if achieved, that will place Japan just behind the EU and China and ahead of Germany (40 million kW) and the US (38 million kW).

The task is not an easy one, but Japan has proved that it can overcome the hurdles and the delays if it can effectively coordinate public and private initiatives. To this end, the role of the bureaucracy is crucial. Japan can in fact rely on very capable public officials, selected from the best and most prestigious universities, but will they be able, as they did in the past, to provide direction, exert the necessary leadership and mobilise the private sector toward the shared goal? Moreover, will they be able to defend Japanese interests in the international arena? This implies not only the promotion of Japanese infrastructures and technology abroad, particularly in Southeast Asia, but also the ability to promote Japanese solutions as international standards. Today, Japan is lagging behind in both areas and in recent years has suffered several setbacks, but it could reverse its course if it can coordinate its efforts effectively.

The Geopolitical Race for Infrastructure Investment. Where Do We Stand?

Alessandro Gili, Davide Tentori

The Global Infrastructure Gap: Why Is It Not Just an Economic Matter?

Estimating the global infrastructure gap is not easy as several variables have to be taken into account while infrastructure investment data is not always up to date. Broadly speaking, the infrastructure gap is the difference between where a country is at today and where it would like to be at a given time.[1] Therefore, it is unlikely to obtain a unique number explaining the investment needed to fill the global shortage of infrastructure investment globally. According to the Global Infrastructure Hub, an initiative sponsored by the G20, current trends of investment in infrastructure reveal a gap of US$400 billion in 2021, which is likely to widen in the coming years should investment fail to keep up with demand.[2] Until 2040, the GI Hub estimated a cumulative gap of US$15 trillion. Energy and the telecommunication sectors are currently the most at risk of being impacted by insufficient investment, respectively with total needs of US$160 and US$57 billion within the next two

[1] N. Cusumano, "Infrastructure gap and drivers for growth", European Investment Bank – SDA Bocconi, 2017.

[2] See outlook.gihub.org

decades. According to estimates by Oxford Economics, the world would need to increase the share of GDP dedicated to infrastructure projects by 0.5% (from 3% in 2016, which is considered as the baseline) to meet current investment needs.[3]

The economic benefits of infrastructure are crucial to unlock long-term economic growth: ageing population, climate change, and the need to replace obsolete assets are the key reason behind effective and modern infrastructure assets as the main driver to support GDP growth whilst increasing growth potential in the medium to long run. Moreover, infrastructure projects can generate employment in the short term, as well as increase competitiveness of the economic system as a whole, provided that problems such as waste, inefficiencies and corruption are avoided.[4] However, the opposite is also true: most countries where investment in infrastructure has been insufficient have registered lower GDP growth and lower employment rates. Channelling resources into infrastructure projects can generate significant countercyclical effects during an economic crisis.[5] At the same time, the long-term financial returns generated by an infrastructure asset over its life cycle should also be taken into account (think, for instance, of the tolls collected by managing a motorway).

However, focusing solely on the economic returns that infrastructure investment can generate would be short-sighted. Infrastructure projects are also instrumental to a country's geopolitical agenda in several ways. First of all, they are intrinsically linked to a country's morphology as they help overcome or bypass geographical barriers. This means that infrastructures

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[3] Oxford Economics, Global Infrastructure Hub, *Global Infrastructure Outlook – Infrastructure investment needs*, 2016.

[4] P. Subacchi, S. Pickford, D. Tentori, and H. Huang, *Building Growth in Europe – Innovative Financing for Infrastructure*, Chatham House Report, Chatham House, September 2014.

[5] A. Belladonna and A. Gili, "Infrastructure Between old and New Trends", in C. Secchi and A. Belladonna (Eds.), *Infrastructure in a Changing World – Trends and Challenges*, Milan, Ledizioni-ISPI, 2019.

can improve and strengthen the relations between central and peripheral regions within a country; thus reducing the gap between central governments and local communities. Secondly, connectivity is a crucial aspect that makes infrastructures crucial from a geopolitical point of view. Energy pipelines, internet cables, intercontinental airports, maritime ports are all sides of a same coin: in today's extremely globalised world, controlling the key "knots" along these networks is of the essence to strengthen a state's geopolitical influence, both at the regional and global levels.[6] Thirdly, the importance of infrastructure assets emerges clearly as they are fundamental to control the extraction, transmission, and distribution of resources such as agricultural commodities (e.g. a railway connecting a mine to a factory) or energy as it happens in the case of oil&gas. In this regard, for instance, the development of energy routes in South East Asia is functional not only to China's, but to South Korea's and Japan's geopolitical influence in the region, too[7] Likewise, Russia's geopolitical influence in Eastern/Northern Europe and the Mediterranean region is still high – despite Moscow's limited economic power – thanks to its control of key pipelines. The recent controversies around the "Nord Stream 2" pipeline, that would allow Russia to provide Europe with natural gas without having to go through Ukraine, are perceived by the US and many NATO members as a potential threat to national and regional security and autonomy.[8] Digital infrastructures are also increasingly important in today's interconnected world and represent a means to exert geopolitical influence: see, for instance, EU's attempts at using Internet cables to strengthen its presence in the Mediterranean region and to counter the

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[6] P. Khanna, *Connectography – Mapping the Global Network Revolution*, Weidenfeld & Nicolson, 2016.

[7] M. Oh, *How energy infrastructure is shaping geopolitics in East Asia*, World Economic Forum, 2018.

[8] B. Schmitt, *Geopolitical weapon: Putin's pipeline nears completion*, Ukraine Alert, Atlantic Council, 14 June 2021.

leadership of the US and China.[9] It transpires that building infrastructure networks is essential to reach strategic and geopolitical objectives that go beyond mere economic returns. What is at stake in today's global infrastructure competition among key powers?

From Biden's Plan to China's BRI and the EU's Connectivity Strategy: Key Geopolitical Implications

The competition for global leadership – from both an economic and geopolitical point of view – plays around two actors : the United States and China. Despite its ability to act as a standard-setter at the international level,[10] the role of the European Union as a truly global power is undermined by its weaker economic leverage and fragmentation among Member States.

Ambitious infrastructure plans are at the core of these players' respective strategies to increase their international projection and gain influence. China can exploit a sort of "first mover advantage" since its "One Belt One Road" strategy was launched in 2013 and can also count on a relatively structured international architecture, with the Asian Infrastructure Investment Bank as its cornerstone. The mission of this multilateral development bank – established in 2014 – is officially aimed at developing Asia by "fostering sustainable economic development, creating wealth and improving infrastructure connectivity".[11] This project was opposed by the US with little success, since most of Washington's allies joined the bank (including other G7

[9] M M. Colombo, F. Solfrini, and A. Varvelli, *Network effects: Europe's digital sovereignty in the Mediterranean*, Policy Brief, European Council on Foreign Relations, 4 May 2021.

[10] A. Bradford, *The Brussels Effect – How the European Union rules the World*, Oxford, Oxford University Press, 2020.

[11] See at Asian Infrastructure Investment Bank, https://www.aiib.org/en/about-aiib/index.html

countries, with the sole exception of Japan) thus contributing to the success of an ambitious example of economic diplomacy put in place by Beijing. The AIIB managed to obtain a solid and robust reputation on financial markets (it holds "triple A" credit ratings)[12] and has approved 130 projects amounting to US$24.9 billion so far. China's initiative – based on a long-term vision to support the country's economic and political expansion well beyond Asia – has attracted interest from over 150 countries as it has targeted an international vacuum originated by the loss of focus and commitment by International Financial Institutions in supporting "hard" infrastructure development.[13] Japan's initiative aimed at defining a set of agreed, international criteria for a "Partnership for Quality Infrastructure" (PQI) (launched during its 2016 G7 Presidency with the support of the World Bank) represented a clear attempt to counter China's dynamism in the Asian region by making sure that infrastructure investments were strongly attached to environmental sustainability, respect for human and workers' rights, and strong and transparent governance mechanisms aimed at avoiding corruption.[14] Launched in 2016 as part of the Strategy for a Free and Open Indo-Pacific (FOIP), with a target of US$110 billion in projects over the four-year period between 2016 and 2020, the PQI immediately doubled its budget to US$200 billion. The uniqueness of this initiative lies in Japan's willingness to base proposals on the national development plans of the various economies. However, the limited fiscal capacity of Japan's public finances has prevented Tokyo from offering large-scale investments, prompting it instead to focus on the quality of the works it finances.

[12] G. Grieger, "Asian Infrastructure investment Bank – How lean, clean and green is the AIIB?", Briefing, European Parliament, 2021.

[13] R. Hass, B. Jones, and J. Masonbrookings (Eds.), "China's Belt and Road: the new Geopolitics of Global Infrastructure Development", Interview by Bruce Jones, Brookings Interview, Foreign Policy at Brookings, 2019.

[14] See World Bank, *Quality Infrastructure Investment Partnership*.

The overall poor quality and lack of sustainability of BRI projects has increasingly become an issue of concern both among recipient countries and in China. BRI investments have sometimes resulted in small and medium-sized countries' growing economic and political reliance on Beijing; ultimately leading some of them – particularly those with previously high rates of public debt — towards a dangerous debt trap, ultimately eroding their sovereignty. Between 2013 (its launch year) and 2020, China totalled US$762.57 billion in global investments under the Belt and Road Initiative, averaging about US$95 billion per year. Within the New Silk Roads framework, Beijing has privileged the energy and transport sectors above all (road, rail, and maritime infrastructure): respectively US$296.7 billion in energy (38.9% of the total) and US$187.06 billion in transport (24.5% of the total). The technology field is also important, albeit with a smaller share, accounting for some US$15.6 billion in investments throughout the BRI's eight-year long life.[15] A turbulent one at that, mainly due to some projects' limited ecological and economic sustainability: according to CSIS, 90% of BRI energy investments go towards fossil fuels, while over US$15 billion were invested in coal between 2013 and 2019 – the most polluting energy source of all.[16] This led President Xto announce the creation of the Belt and Road International Green Development Coalition during the second summit BRI summit in April 2019, an alliance of 134 partners that aims to make BRI investments sustainable and in line with the UN's 2030 Agenda for Sustainable Development.

In fact, in 2016, President Xi committed to create a green and sustainable BRI, with a key role played by Chinese banks involved in funding BRI projects (such as the NDB, AIIB, the Silk Road Fund). Accordingly, in April 2019, the Singapore branch of the Industrial and Commercial Bank of China issued

[15] See Heritage Foundation, China Investment Tracker. See *China Global Investment Tracker*, Heritage Foundation.

[16] J. Nakano, *Greening or Greenwashing the Belt and Road Initiative?*, Center for Strategic and International Studies (CSIS), May 2019. 9

the first green BRI Interbank bondworth US$2.2 billion. Despite these formal efforts, however, turning the BRI "green" would be trickier than ensuring a sustainable transition and carbon neutrality in the mainland.[17]

On the other hand, the United States lagged behind China during the Trump administration. His mandate was characterised by a substantial withdrawal from foreign affairs: as a result, a forward-looking, structured vision on infrastructure investment as a key component of America's geopolitical projection went missing. The US Strategy was indeed uncoordinated and somehow half-hearted. In October 2018, at the behest of President Trump, the Build Act was passed, which aimed to streamline various US development agencies' work and create the US$60 billion US International Development Finance Corporation (USIDFC), set to specifically counter Chinese investment in the Indo-Pacific.[18] Afterwards, the Blue Dot Network – announced in late 2019 and temporarily halted by the pandemic – brought together the United States, Japan, and Australia in an infrastructure alliance dedicated primarily to the Pacific.[19] The goal was to offer a financing scheme that is more transparent than China's and more attentive to environmental sustainability dynamics, while strengthening cooperation between public and private investment.

Joe Biden's strategy is remarkably different: through his "American Jobs Plan" – launched at the end of March 2021 – the US Government has committed to increase public investment in domestic infrastructure by US$2 trillion in order to support economic growth and improve the quality of US assets (which currently rank 13th globally).[20] However, it is worth noting that

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[17] A. Politi, *How Green is China's Belt and Road Initiative?,* IAI Commentary, IAI, April 2021.

[18] D. Runde and R. Bandura, The BUILD Act Has Passed: What's Next?, Center for Strategic and International Studies (CSIS), October 2018.

[19] K. Arha, *A hidden key to the G7's infrastructure ambitions: Blue Dot Network*, Atlantic Council, June 2021.

[20] The American Jobs Plan, The White House, Factsheet, 31 March 2021.

Biden plan's focus is much more inward-looking as it is primarily targeted at improving the long-term growth potential of the American economy. Moreover, over the last few years the US administration has enforced investment regulations which tend to have protectionist effects and prioritise domestic companies over foreign competitors.[21] Under Donald Trump, the US also showed less interest in influencing key International Financial Institutions (IFIs) that it has traditionally controlled like the World Bank, reducing both the scope and funding available for infrastructure strategic projects (particularly in developing countries) that would counter China's expansionary plans.[22] Therefore, America's inaction at the international level has created a geopolitical vacuum China has benefited from, pulling European countries towards Beijing's sphere of influence, too. The situation might change and lead at least to a rebalancing with the Biden administration strengthening Transatlantic ties with Europe on top of supporting initiatives in South East Asia, including the relatively new "Quadrilateral Security Dialogue" (QUAD) with Australia, India, and Japan, or the already well-established ASEAN Forum.[23] Whether these initiatives will lead to more direct US involvement in infrastructure projects in the region is still too early to tell; but the White House's plans to reduce China's geopolitical influence in the Eurasian region have been made explicit.

In September 2018, the EU adopted the joint communication "Connecting Europe and Asia – Building blocks for an EU strategy".[24] The Strategy proposes that the EU engage with

[21] For instance, through the "Foreign Investment Risk Review Modernization Act" issued in 2018 the US strengthened and modernised the Committee on Foreign Investment in the United States (CFIUS), with a particular view to counter China's potential hostile FDIs in the American territory.

[22] J. Hillmann and D. Sacks, "China's Belt and Road: Implications for the United States", Independent Task Force Report no. 79, Council on Foreign Relations

[23] A. Mosca, "Indo-Pacifico: il ritorno dell'America (vincente)?", ISPI Commentary, ISPI, 15 April 2021.

[24] European Commission, "Connecting Europe and Asia - Building blocks for an EU Strategy", JOIN (2018) 31 Final, September 2018

its Asian partners through a sustainable, comprehensive, and shared rules-based approach to connectivity, leveraging existing and planned EU networks. The Strategy itself acknowledges the presence of a significant connectivity investment gap and recognizes the need to mobilise and strengthen cooperation with private investors, national and international institutions, and multilateral development banks. Analysts have interpreted the document as the EU's response to China's Belt and Road Initiative. An interpretation supported especially in light of significant Chinese investments in Central and Eastern Europe through the 17+1 initiative that could undermine the existence of a common European position in terms of infrastructure connectivity.

A contrast between the EU and China manifested in the March 2019 Strategic Outlook, where the Commission defined China as a "systemic rival" for the first time.[25] The document, which updated the previous 2016 Strategy on China, assumed that Beijing was not only a trading partner, but also a global power with different goals and values from the Union's. In addition to economic issues, in fact, the Commission supports the commitment to peace and security in the Indo-Pacific region, expressing concerns around Chinese behaviour and territorial claims brought forward by Beijing. Also, on the subject of Chinese investments, European perplexities were (and remain) considerable, in particular with regards to governance, sustainable development, transparency of financing, and the lack of reciprocity and a level playing field. As a sort of response to the BRI, Brussels then launched a series of initiatives to engage East Asian countries in an infrastructure development program.

In 2019, the EU and Japan launched the EU-Japan Partnership on Connectivity and Quality Infrastructure,[26] an alliance based on sustainability and adherence to high quality

[25] European Commission, *EU-China. A Strategic Outlook*, European Commission and HR/VP contribution to the European Council, 12 March 2019.

[26] See The Partnership on Sustainable Connectivity Between the European Union and Japan, 27 September 2019.

standards, modelled around the G20 Principles for Quality Infrastructure Investment outlined by the Osaka meeting. On top of traditional infrastructure, digital connectivity issues and cyberspace security are also at the core of this initiative.

In May 2021, the EU signed a partnership with India, Beijing's regional rival.[27] Already in its preamble the EU-India Connectivity Partnership reiterates the founding values of democracy and rule of law – an implicit message to Beijing – and focuses on the development of infrastructure networks, energy, and digital. Although with a clear focus on the Indo-Pacific region, the partnership with India includes other geographical areas that have seen a growing Chinese presence over the years, such as Central Asia and Africa. It is precisely in Africa that the increase in Chinese investment has pushed Brussels to strengthen its support tools for development in the region. After twelve years of activity where it played a role in leveraging infrastructure investments of over €11 billion,[28] in 2020 the EU-Africa Infrastructure Trust Fund became part of the broader Africa-EU Cooperation on Transport and Connectivity,[29] the component of the European strategy for Africa[30] dedicated to investments in infrastructure and digital connectivity.

On 12 July 2021, the Council approved conclusions on "A Globally Connected Europe",[31] intended to foster a geostrategic and global approach to connectivity. By Spring 2022, when a new Joint Communication will be adopted, the EU will concretely start high impact and visible projects to rival China's BRI. In particular, the EU – while reaffirming the principles

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[27] See European Council, EU-India Connectivity Partnership, 8 May 2021.

[28] Data available on European Union-Africa Infrastructure Trust Fund.

[29] European Commission, *Towards an enhanced Africa-EU Cooperation on Transport and Connectivity*, Report by the Task Force on Transport and Connectivity.

[30] European Commission, Joint Communication of the European Parliament and the Council, Factsheet, "Towards a Comprehensive Strategy with Africa", Brussels, 9 March 2020.

[31] European Council, A Globally Connected Europe, 12 July 2021.

of a sustainable, comprehensive and rules-based connectivity – would move beyond the 2018 EU-Asia Connectivity Strategy to build a "globally connected EU", which would focus investments especially towards Africa and Latin America, key destinations for Chinese investments. Moreover, the Council supports Connectivity Partnerships with like-minded countries and regions and encourages the operalization of existing partnerships with Japan and India. Finally, the European Union fully endorses the G7 plan to Build Back Better for the World (B3W).

The Council intends to blend public and private resources, including EU and member-country-level financial instruments, export credits, loans, and guarantees as well as engaging the European Investment Bank and the European Bank for the Reconstruction and Development. The main challenge will lie in financing large-scale sustainable infrastructure whilst scaling up the efforts for technical assistance in low- and medium-income countries and creating sound regulatory frameworks and shared standards.[32]

The G7 Response with the Build Back Better World (B3W)

The first step of the common front of democracies, proposed by President Biden during his election campaign, seemed to materialize on 13 June in the G7 Summit's Final Communiqué in Cornwall. For the first time, major industrialised economies agreed to a coordinated plan for industrial investment in low- and middle-income countries – the Build Back Better for the World (B3W). This move formalizes an attempt to curb Chinese primacy in investing in roads, bridges, railways, energy, water, and digital infrastructure in developing countries through the Belt and Road Initiative (BRI).

[32] S. Lau, "EU starts work on rival to China's Belt and Road Initiative", *Politico*, 6 July 2021.

The Build Back Better for the World Plan is the first attempt by Western countries to reduce the infrastructure gap that persists in developing countries – estimated by the G7 to be at over US$40 trillion – and secure new sources of quality and sustainable infrastructure investment.[33] The G7 countries' ultimate goal and the main allies is to coordinate to mobilise private capital in four areas considered crucial: climate, health, digital technologies, equality (including gender equality), involving, in particular, multilateral and national development finance institutions. Investments must follow, in particular, the following criteria:

- Focus on transparency and financial, environmental, and social sustainability, in order to ensure a positive impact for recipient countries and local communities.
- Good Governance and High Standards, in order to ensure long-term benefits and appropriate use of resources to respect social and employment safeguards, environmental standards, and ensuring good anti-corruption practices, particularly in the construction phases.
- Climate-Friendly, as all investments will be made in such a way as to achieve the objectives of the Paris Agreement (COP21).
- Long-term Strategic Partnership. Investments will need to generate long-term development impact, including through the establishment of a G7 Task Force to coordinate and harmonize the efforts of different countries, increasing their impact.
- Mobilise private investment through financing for development. This objective should be achieved by increasing the financial instruments available to catalyse new investment in infrastructure.
- Strengthen the impact of multilateral public finance. It is recognised that multilateral development banks and

[33] Carbis Bay G7 Summit Communiqué, "Our Shared Agenda for Global Action to Build Back Better", Cornwall 2021.

> other International Financial Institutions (IFIs) have embedded the best environmental and social standards in the design and construction phases of their activities. Therefore, the work multilateral development banks and other IFIs are already undergoing for the identification of standards – i.e., quantitative and qualitative criteria around what constitutes sustainable infrastructure and what funding it can benefit from – will be reinforced. Also fundamental is the reference to loan sustainability, which must be repaid through a path that is sustainable for the debtor country.

The agreement appears to move in the direction of the Principles for Quality Infrastructure Investment (QII) announced at the 2020 G20 Summit in Osaka. The final G7 document also recognises that, while global in their scope, the Plan's investments will be directed by individual G7 countries in their geographic areas of greatest interest. No figures have been mentioned yet, as the G7 Communiqué merely defines that financial efforts will allow for the catalysation of hundreds of billions of dollars over the next few years. Chancellor Merkel announced that the first concrete infrastructure projects should be identified during the G7 German Presidency in 2022 and following the work of the dedicated Task Force.[34]

The G7 also reiterated the commitment made in 2009 to mobilise 100 billion per year through public and private sources by 2025 for investments that can be grouped under climate finance, i.e., aimed at favouring the energy transition of low-income countries. Within this framework, a New Deal for Africa will be central to strengthening the partnership and development prospects of the continent.

To achieve these goals, the G7 emphasises the role of multilateral development banks and national development

[34] "Germany's Merkel hopes for G7 infrastructure plans in 2022", *Reuters*, 13 June 2021.

banks in adopting strategies for mobilizing capital, especially through the blending of public and private resources and greater cooperation with funds such as the Green Investment Fund and Climate Investment Funds.

The lack of a clear definition of the Plan's financial scope is certainly a first element for strong criticism. Although a subsequent Task Force will be able to identify the Plan's financial framework, the lack of a Joint Infrastructure Fund between the G7 countries could pose a structural limit to its effectiveness.

Secondly, it seems unlikely that industrialised countries, already hard hit by the coronavirus crisis and with extremely high debt/GDP ratios, will be able to finance very risky projects from a financial point of view and with low returns. China, through the BRI, has assumed the risk of investing in countries with high political, economic, and financial risk: to do so, it has required extremely stringent conditions, including the transfer of ownership of strategic and dual-use (civil and military) infrastructures under Beijing's control. Just think of what happened with the port of Hambantota in Sri-Lanka, where failing to pay the loan back allowed China to acquire control for 99 years.[35] Moreover, in 2016 neither the EU nor any Western partners had intervened with adequate investments in the Greek Port of Piraeus, while the Chinese COSCO was involved through significant investments, immediately after the accession of the Hellenic country to the Chinese BRI. On the contrary, by in 2019 the perspective changed: the European Investment Bank (EIB) has intervened by financing with €140 million the enlargement of the Port, seeking to increase the weight of European capital in the activity of the maritime infrastructure.[36] Another emblematic case is Montenegro, where Beijing has provided funding for a freeway, previously denied by the European Union precisely because of the

[35] K. Stacey, "China signs 99-year lease on Sri Lanka's Hambantota port", *Financial Times*, 11 December 2017.

[36] European Investment Bank, *Greece: EUR 140 million EIB backing for Port of Piraeus transformation*, 11 November 2019.

project's reduced economic yield. However, the impossibility of completing it has plunged Podgorica into a debt spiral, with the risk of having to sell parts of its territory given as collateral to Chinese financial institutions.[37]

Third element: it is doubtful whether the G7 countries will be able to guarantee loan conditions as competitive as China's. Although Beijing's investments have caused problems with over-indebtedness in countries with already high levels of debt-to-GDP ratio, the rates expected from Chinese investments are low, given the high political and credit risk of the countries receiving the investments. In addition, the high environmental and governance standards envisaged by the Build Back Better for the World (B3W) plan will entail higher costs and technical capacity for the design and construction of investments. On the other hand, even developing countries are increasingly demanding better quality in terms of environmental and social standards for infrastructure investments in their countries: this could lead them to choose Western investments over Chinese ones.

Finally, the positions of the G7 member countries are not univocal with regards to China. Though the United States has a very firm stance towards Beijing, other countries – including Italy and Germany as well as the United Kingdom – have more ambiguous positions. In 2018, Rome signed a Memorandum of Understanding (MoU), becoming the first G7 country to join the BRI, although the Draghi government announced a review of the agreement[38] (and previously blocked the acquisition of an Italian semiconductor company by China through the Golden Power tool[39]). Meanwhile, Berlin boasts a significant trade surplus with China and London took a position of dialogue

[37] G. Fruscione, *Montenegro: l'insostenibile leggerezza del debito*, ISPI Commentary, ISPI, 20 April 2021.

[38] "Riesamineremo il nostro accordo con la Cina sulla Nuova Via della Seta", *AGI*, 14 June 2021.

[39] "Il governo Draghi usa per la prima volta il Golden power: bloccata l'acquisizione cinese di un'azienda lombarda dei semiconduttori", *la Repubblica*, 9 April 2021.

around the installation of 5G infrastructure with non-critical Chinese components, even though the UK Government has adopted recently a tougher stance.[40]

The G20's Role for Infrastructure Cooperation

The upcoming G20 Summit in Rome will be crucial to verify other major world economies' position on infrastructure issues. The 2019 G20 Osaka Summit marked the adoption of an initial set of principles for defining quality infrastructure (preserving the sustainability of public finances; increasing economic efficiency in view of life-cycle cost; integrating environmental and social considerations, including women's economic empowerment; building resilience against natural disasters and other risks; and strengthening infrastructure governance).[41]

The following year, the 2020 Riyadh G20 focused on technology as a tool to improve the economic efficiency of infrastructure and its environmental impact. Perhaps most important, however, was the call to avoid duplication and overlap in infrastructure investments, with greater coordination at the international level and greater involvement of multilateral development banks and international financial institutions.[42]

To reduce the large, existing infrastructure gap and build quality infrastructure that contributes to sustainable development, it is indeed crucial to efficiently allocate available financial resources, coordinate the various existing funds for climate resilience, and promote the blending of public and private resources through Development Financial Institutions' fundamental activity. In this sense, the G20 remains the privileged forum to find a common ground among the different

[40] L. Kelion, "Huawei 5G kit must be removed from UK by 2027", *BBC News*, 14 July 2020.

[41] G20, *G20 Principles for Quality Infrastructure Investments*, Osaka, 2019.

[42] G20, Riyadh Final Communiqué, Leaders' Declaration, Riyadh Summit, 21 November 2020.

several national and international infrastructure plans and share a minimum set of ESG indicators that allow the development of sustainable infrastructure as an asset class. The European Union, in this sense, could play a key role as an international powerhouse for setting quality environmental, social and operational standards to be endorsed at international level: in July 2021 Brussels has indeed elaborated a new Sustainable Finance Strategy, a European Green Bond Standard proposal and a Delegated Act (supplementing article 8 of the Taxonomy Regulation) on the information companies have to disclose about how sustainable their activities are.[43] A higher involvement of the private sector and the development of some kind of quality criteria for quality infrastructure has been reiterated by the G20 Roadmap to Develop Infrastructure as an Asset Class,[44] the G20/OECD Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure[45] and during the G20 Infrastructure Investors Dialogue.[46] In fact, the ultimate objective must remain that of reducing the risk of investments in infrastructure and attracting more private investors to meet a challenge that is not only geopolitical, but above all economic, social, and environmental. Infrastructure is a crucial economic tool for long-term economic growth and an escalating geopolitical competition could undermine its primary role. It is essential that in the G20 framework further steps should be taken to ensure a level playing field for infrastructure investment, ultimately expanding the chances for cooperation and reducing the scope for greater competition. China, after all, is also a member of the G20.

[43] See European Commission, "Strategy for financing the transition to a sustainable economy", 6 July 2021.

[44] G20/OECD, Roadmap to Infrastructure as an Asset Class, 2018.

[45] G20/OECD, *Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure*, 24 July 2020.

[46] G20, "Financing Sustainable Infrastructure for the Recovery, G20 Infrastructure Investors Dialogue 2021", Virtual Conference, 3 June 2021.

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Giacomo Luciani has created and is responsible for the scientific content of the Master in International Energy at the Paris School of International Affairs of SciencesPo. He also teaches at the Graduate Institute of International and Development Studies in Geneva and in the Master of Science in International Trading at the University of Geneva. In 2010-13 he was Global Scholar at Princeton University. His MOOC "Politics and Economics of International Energy" is available on Coursera website. His work has focused on the political economy of MENA and global energy issues. His latest co-edited book, *When Can Oil Economies Be Deemed Sustainable?* (2020).

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