International Transport Forum

SIPA
Sustainable Infrastructure Programme in Asia

Enhancing freight transport decarbonisation through analytical frameworks

Applications to Central and Southeast Asia

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The Sustainable Infrastructure Programme in Asia

This paper is part of the Sustainable Infrastructure Programme in Asia (SIPA), funded by the German International Climate Initiative (IKI) and led by the OECD. SIPA aims to support countries in Central and Southeast Asia in their transition towards energy, transport and industry systems aligned with the Paris Agreement and Sustainable Development Goals.

The ITF leads the transport component of the SIPA programme (SIPA-T). The SIPA-T project helps decision makers in Central and Southeast Asia by identifying policy pathways for enhancing the efficiency and sustainability of regional transport networks. Project outputs include two regional studies that explore opportunities to improve the connectivity, sustainability, and resilience of freight transport systems in Central and Southeast Asia.

This paper is the second in a series of four ITF expert working papers that collectively provide the methodological foundation for the two SIPA-T regional freight transport studies. The full series includes the following papers:

1. *Enhancing freight transport connectivity through analytical frameworks* (Ruth Banomyong)
2. *Enhancing freight transport decarbonisation through analytical frameworks* (Alan McKinnon)
3. *Enhancing freight transport resilience through analytical frameworks* (Jasper Verschuur)
4. *Evaluating the relationships between connectivity, decarbonisation and resilience in freight transport* (Alan McKinnon)

Access these papers, more information and other SIPA-T project deliverables:

https://www.itf-oecd.org/sustainable-infrastructure-programme-asia-transport

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Summary

Freight transport is responsible for 56% of energy-related CO_2 emissions from domestic transport in Asian countries. It will likely account for most of the rise in transport-related emissions in these countries over the next 25 years. This is not reflected in the attention it receives in national and regional decarbonisation strategies, as they are typically dominated by personal movement. The resulting policy bias is partly attributable to a lack of understanding of longer-term logistics trends and how well-targeted policy initiatives can mitigate their carbon impacts. This paper aims to help public policy makers monitor these trends and conceptualise the related decarbonisation options. It does this by scoping the subject, outlining several analytical frameworks and identifying a range of metrics that quantify the scale of the carbon-reduction challenge and the main ways of addressing it.

Freight decarbonisation targets, strategies, and regulations must be tailored to a country's economic and geographical circumstances. These vary considerably within and between Central and Southeast Asia, the two regions with which the ITF SIPA project is primarily concerned. The paper adopts a macro-logistics perspective on this variability, recognising the close inter-relationship between freight transport and the changing nature of production and logistic systems. It asks whether these countries must inevitably follow the same development pathways to high-carbon logistics exhibited in Europe and North America or if alternative trajectories might restrain increases in carbon emissions with minimal economic penalty.

The paper advocates adopting a life-cycle approach to decarbonising freight transport in the two regions. This supplements the measurement of vehicle tailpipe emissions with analyses of emissions from the energy supply chain and those embodied in transport infrastructure. Such an approach is particularly apposite for countries at an earlier stage in their development when transport infrastructure is being substantially upgraded.

An iterative 10-stage framework outlines how governments can systematically devise and deploy a freight transport decarbonisation strategy. This is based on a scheme initially developed for businesses. It starts with political commitment and leads through nine other processes (each beginning with the letter C), culminating in implementing the strategy and its subsequent recalibration in the light of ex-post evaluations. Intervening stages include measuring freight transport emissions at a macro-level, committing to realistic reduction targets and considering relevant policy options. Three classificatory frameworks are proposed for these options, of which the so-called "five lever" framework is recommended and summarised below.

Collaboration is a key element in any decarbonisation strategy. For national governments aiming to decarbonise freight distribution, this can involve collaboration with other countries, international organisations, sub-national administrations and business stakeholders.

At the costing stage in the process, marginal abatement cost (MAC) analysis is encouraged as a means of assessing both the potential CO_2 savings from particular initiatives and their relative mitigation costs. Assembling these initiatives into a coherent package is a country-specific exercise and must take account of synergies, trade-offs and time scales for delivery and impact. Governments' role under the carbon offsetting heading can include the validation and policing of schemes used by businesses to compensate for logistics-related emissions.

Much of the paper concerns the five levers that governments can pull to decarbonise freight transport. Several policy initiatives and macro-level metrics are identified for each lever. The management of freight transport demand offers limited policy leverage in Central and Southeast Asian countries as they are at a phase in their economic development when freight tonne-kilometres and GDP trends are closely correlated, and the latter is strongly prioritised. On the other hand, freight modal shift is a declared policy objective in many of these countries, though it has been very difficult to achieve, particularly concerning rail in a continent where water-borne transport is often the main low-carbon alternative to road.

Macro-level statistics on the utilisation of freight capacity are seriously lacking across the two study regions. Available data shows widespread under- and over-loading of road freight vehicles, both carrying a substantial carbon penalty. Statistical monitoring of freight energy efficiency is also inadequate, with policy interventions targeted more at cars and buses than trucks. The paper, nevertheless, argues that a combination of driver-, vehicle- and operations-focused initiatives can significantly cut energy consumption. Various aspects of the transition to lower carbon energy in the freight transport sectors of Central and Southeast Asia are examined, focusing on conditions that must be satisfied to achieve their repowering with low-carbon electricity.

The latter part of the paper broadens the perspective by including the measurement and reduction of infrastructure-related emissions. It shows how infrastructural investment strongly influences the application of the five freight decarbonisation levers. It then discusses four issues related to the inclusion of infrastructural emissions in a life-cycle analysis of freight transport decarbonisation:

- Where should a boundary be drawn around the calculation of these emissions?
- How can infrastructural emissions be reduced at different stages in their life cycle?
- How can infrastructural and operational emissions be integrated into a life-cycle assessment?
- How might the inclusion of infrastructural emissions influence freight decarbonisation policies?

The paper concludes with an answer to the question posed at the outset, namely, to what extent can countries in Central and Southeast Asia follow a lower-carbon path of logistics development than that pursued by high-income countries over the past 50 to 60 years. It suggests that the core spatial, operational and market processes making logistics more carbon-intensive generate so much economic benefit from scale economies, lower inventory, greater productivity and higher sales that they are very difficult to constrain or modify. Their adverse environmental effects can, however, be significantly reduced by a series of mitigation measures, including investment in multi-modal transport infrastructure, land use planning policies that prioritise a clustering of logistics development, particularly at rail- and waterway-connected sites, the pursuit of load consolidation strategies, and an accelerated transition to more energy-efficient, low-carbon vehicles, vessels, and locomotives.

Introduction

The term “sustainability” is widely used and defined in many different ways. The UN adopted an exceptionally broad definition in declaring its seventeen Sustainable Development Goals (SDGs). More widely used in business and government circles is the “triple-bottom-line” (TBL) definition, which focuses on the interaction between economic, environmental and social goals.

This paper is mainly concerned with the environmental dimension, though not with all negative environmental externalities. It will concentrate on carbon emissions from freight transport and examine how they can be reduced, particularly in the countries of Central and Southeast Asia. Although no explicit reference will be made to most of the UN SDGs and the social aspects of the TBL definition, it is important to note that the decarbonisation of freight transport can yield a range of sustainability co-benefits. These co-benefits can strengthen the case for cutting freight emissions, particularly in countries where the movement of goods seriously pollutes the air, is a major cause of road fatalities, exacerbates traffic congestion and is responsible for an unnecessarily high share of energy consumption.

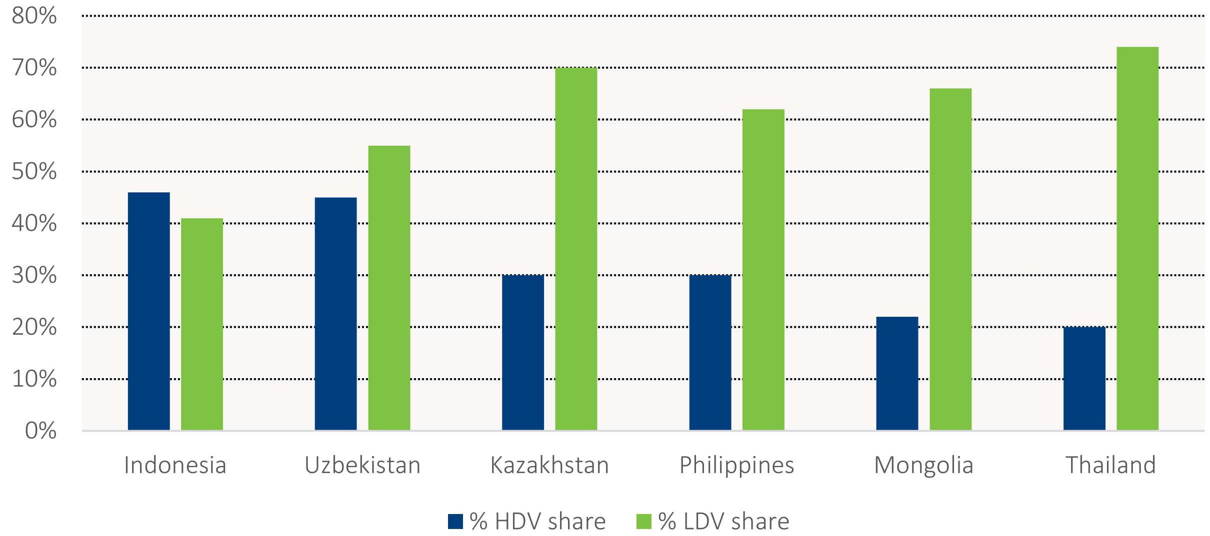
Freight accounts for 56% of energy-related CO_2 emissions[1] from domestic transport in Asian countries, a significantly higher proportion than in the world as a whole, which is estimated to be around 42% (Gota and Huizenga, 2023; ITF, 2021). ITF modelling also predicts that Asian transport emissions will, on a business-as-usual basis, rise by 48% between 2015 and 2050, with the bulk of the growth coming from freight operations. One would, therefore, expect freight decarbonisation to feature prominently in the climate policy agenda for transport in these countries.

On the contrary, in major policy-making areas, “there is far more coverage of passenger transport-related measures than freight transport-related measures” in government documentation (Gota and Huizenga, 2023). One report on the decarbonisation of Asian transport has described freight as the “neglected child of transport decarbonisation” (Council for Decarbonising Transport in Asia, 2022). This policy bias, which is also exhibited in other parts of the world, can be attributed to various factors, including a lack of understanding of logistics operations, government transport statistics offering “a much deeper insight into patterns of personal travel than into the workings of the freight transport system” and the fact that freight “does not vote and usually gets limited exposure in national and local media” (McKinnon, 2019).

Freight’s relatively large share of total transport emissions in Asian countries is mainly due to their lower levels of car ownership. In APAC countries, heavy-duty vehicles (i.e. trucks) account for a larger share of transport emissions (35%) than light-duty vehicles (i.e. cars) (27%) (Asian Transport Outlook, 2023). The relative proportion of emissions from HDVs and LDVs varies widely by country. In the case of four of the six Southeast and Central Asian countries on which this study focuses, the HDV share is significantly below the APAC average (Figure 1).

[1] In the remainder of the paper, all references to emissions will be to energy-related CO_2 emissions.

Figure 1. Relative shares of road well-to-wheel CO_2 emissions from heavy-duty and light-duty vehicles



Notes: HDV = heavy-duty vehicles. LDV = light-duty vehicles.

Source: Asian Transport Outlook (2023).

Differences in the proportion of emissions emanating from the freight sector are one of many macro-level variables that need to be considered when devising national freight decarbonisation plans. Freight decarbonisation targets, strategies and regulations need to be tailored to the economic and geographical circumstances of the country or region. The two Asian subregions contain countries widely varying in size, topography, resource endowment, average income level, transport infrastructure, pattern of trading links and logistics market maturity.

The last of these variables is particularly relevant as freight movement in most countries is now planned and managed within a logistics framework. This recognises the close inter-relationship between freight transport, inventory management, storage, materials handling and related information processing. Over the 60 years during which this logistical approach to freight transport evolved, the main focus has been on the strategies and activities of individual businesses.

Over the past decade, this “micro-logistics” perspective has been supplemented by the development of “macro-logistics”, pitched at a national level and whose “strategic goal” is “to lower the total cost of ownership of goods on a macro-economic scale to improve societal well-being and ecological sustainability, implemented through balanced logistics policy, appropriate infrastructure provision and systemic management” (Havenga et al., 2020). The relationship between macro-logistics and the environmental sustainability of freight transport at the national level was examined by Havenga (2015). This paper takes a macro-logistics view of freight decarbonisation, though it argues that the implementation of national government climate policy must also pay due regard to managing logistics processes at a micro level.

Many studies of the carbon impact of freight movement are concerned only with vehicle tailpipe emissions. Confining the analysis to these so-called “tank-to-wheel” (TTW) emissions ignores a range of other freight-related emissions that can collectively represent a substantial proportion of the actual carbon footprint of freight activity. In a seminal paper, Facanha and Horvath (2007) made the case for adopting a

Life Cycle Approach to measuring freight emissions, comprising “all life cycle phases of vehicles, transportation infrastructure and fuels”. They demonstrated how this could be done using data from the United States. Bäckström (2017) classified five “system boundaries” (SBs) around the measurement of freight emissions: TTW emissions (SB1), well-to-tank (WTT) emissions from the upstream energy supply chain (SB2), emissions from the maintenance of vehicles and infrastructure (SB3), emissions from their manufacture and construction (SB4) and emissions associated with the management and administration of the freight sector (SB5).

Some large logistics businesses now measure and report emissions across all these boundaries, but as yet, few, if any, macro-level assessments have become this holistic. The move from TTW to well-to-wheel (WTW) emission measurement and reporting is now well underway. Monitoring and forecasting trends in WTW emissions are critical to managing the energy transition, particularly for countries such as Vietnam (Gonçalves and Kaldjian, 2021), in which the energy mix is rapidly shifting to renewables.

Data on the level of embodied emissions in freight vehicles of varying ages and powertrains can also help policy makers devise policies on fleet renewal. Recent research by Iyer et al. (2023) highlights the importance of such information. Their comparison of life-cycle emissions from medium and heavy-duty trucks with diesel, electric, fuel-cell and hybrid powertrains produced and used in the United States over a 14-year life-span reveals that embodied emissions in low-carbon vehicles with electric and fuel-cell powertrains were significantly higher than those in diesel-powered vehicles, however, on a full life-cycle basis the former yielded “substantial GHG reductions”. However, this paper does not attempt to relate the results of life-cycle analyses of truck emissions to freight decarbonisation in Central or Southeast Asia. Such an analysis will require dedicated research.

Measurement of emissions from the construction, maintenance and use of road and rail infrastructure has been the subject of numerous studies in recent years. The case for broadening the scope of emission measurement to include these infrastructure-related impacts is particularly strong in emerging markets, such as those in Central and Southeast Asia, for several reasons:

- These countries are often at a stage in their economic development when transport infrastructure is being rapidly upgraded, and this process accounts for a significant share of capital investment and annual carbon emissions.
- The long life of infrastructural assets means that the emissions embodied in them today have a long carbon legacy, influencing longer-term lifecycle and “carbon payback” calculations. As the OECD (2019) acknowledges, Central Asian countries still have the “opportunity to promote infrastructure projects compatible with sustainable development goals or could lock in carbon-intensive technology and unsustainable development patterns for decades to come”. Decisions made today on allocating investment between road, rail and waterway networks and their design standards can constrain freight modal split and the overall carbon efficiency of freight operations well into the future.
- Given the long-term carbon impact of infrastructure planning, governments and the contractors they employ should adopt low-carbon construction practices and materials to minimise embodied emissions.
- Multilateral development banks (MDBs), which are funding much of the transport infrastructure development in these countries, now attach high importance to carbon emissions in their investment appraisals.

For these various reasons, it is encouraging that CAREC (2020) has committed to placing a "strong focus on life-cycle costing and quality for more sustainable infrastructure investments" in Central Asia.

A critical question that this paper will address is the extent to which macro-logistics in the emerging markets in Asia might be able to follow different, lower-carbon pathways from those pursued in North America and Europe. If this were possible without harming a country's economic development prospects, it might allow some lower-income countries to avoid the same degree of "logistical lock-in"[2] to high-carbon freight transport systems (McKinnon, 2023). An attempt will be made to answer this question theoretically and with reference to the development experience of several Asian countries and elsewhere.

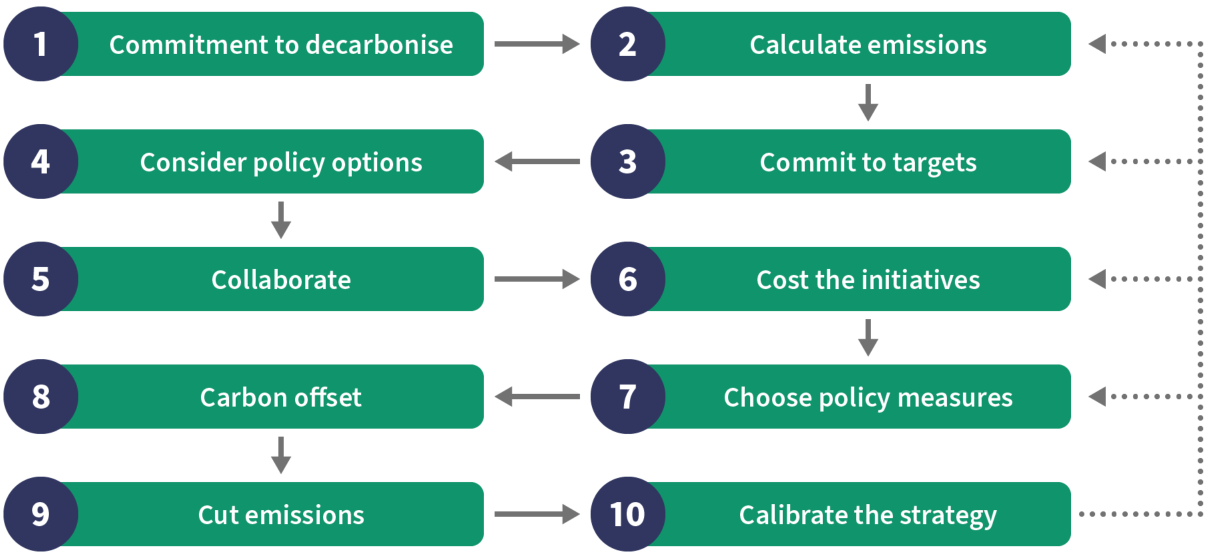
The remainder of the paper is split into four sections. The next section outlines a framework for developing a government decarbonisation strategy for freight transport, while the following section explores in detail each of the five policy levers that governments can pull to achieve this decarbonisation. The last section broadens the scope of the analysis to examine freight transport's share of infrastructural emissions. The paper then ends with several general conclusions.

[2] This occurs when investment in logistics assets and systems constrains modifications to the planning and operation of freight transport in the short- to medium-term.

Developing a national freight transport decarbonisation strategy

Figure 2 outlines a ten-stage framework that governments can use in the systematic development of a freight transport decarbonisation strategy. As each stage has an English word beginning with the letter C, it is called the 10C approach. It is adapted from a framework initially conceived for use in a corporate setting (McKinnon, 2018). It is essentially an iterative framework, as the ninth stage involves implementing the strategy, and the tenth stage is recalibrating the procedure. The feedback loops represent a learning and refinement process where emission measurement, targets, costing, and policy instruments are adjusted in light of experience. Each of the ten stages will be briefly summarised.

Figure 2. The 10C framework for developing freight decarbonising strategy



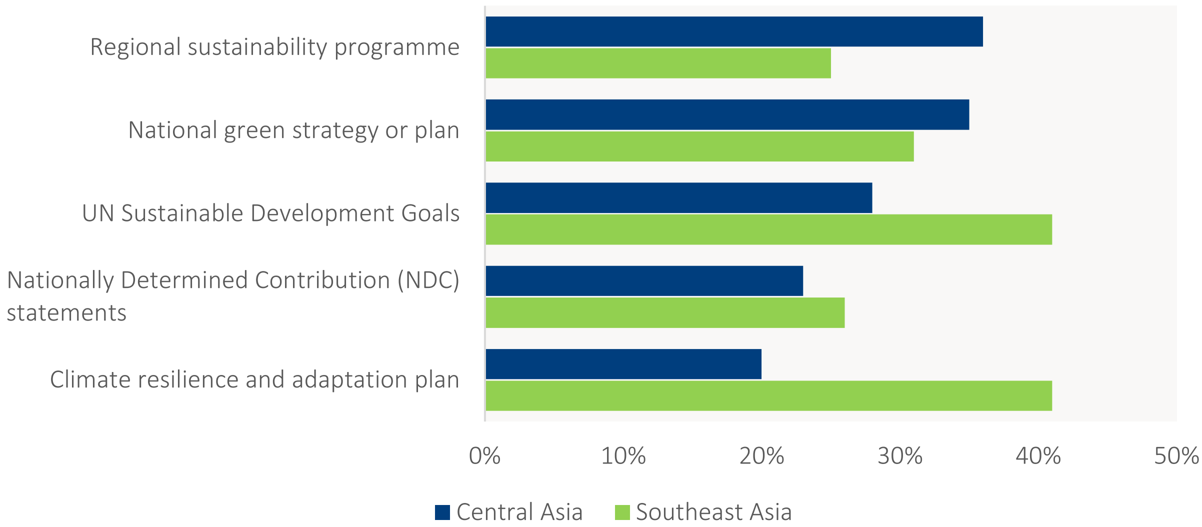
Commit to decarbonise freight transport

A survey of officials in governmental organisations in Central and Southeast Asian countries for the ITF-SIPA project enquired about the current representation of sustainability/decarbonisation measures in freight transport strategies. Just over a third of respondents in both regions indicated that environmental impacts were being incorporated into national freight planning and transport infrastructure design. This suggests that many organisations in both regions have yet to adequately factor environmental externalities into their freight transport and infrastructure planning. It also casts doubt on the current level of commitment to decarbonising freight transport.

This commitment can be expressed nationally in political manifestos and legislation or internationally by a country becoming a signatory to regional or global agreements. All the countries in Central and Southeast Asia are signatories to the 2015 Paris Agreement on Climate Change, which requires them to submit Nationally Determined Contribution (NDC) statements to the UNFCC outlining their plans to cut GHG emissions. A review of the transport content of NDCs revealed that only 13% made any specific reference to freight transport (Gota, 2016), though this is likely to substantially underestimate the degree of government commitment to freight decarbonisation, particularly among Asian countries. Across a group of fifteen Asian countries, only one in nine climate-related transport measures mentioned in national policy documents are listed in NDC statements (Gota and Huizenga, 2023).

The ITF-SIPA survey also asked officials in the two regions which high-level strategic environmental or climate frameworks are used to guide freight infrastructure planning in their countries (Figure 3). The results indicated that the UN Sustainable Development Goals were the most widely used framework, particularly in Southeast Asia. NDC statements were less commonly used, confirming the observation of Gota and Huizenga (2023). Responses from the two regions revealed a wide disparity in the degree to which freight infrastructure planning is related to climate resilience and adaptation planning and regional sustainability programmes. Overall, the percentage of responses was relatively low, suggesting that, across both regions, commitments to decarbonise freight transport could be much more firmly anchored in environmental and climate frameworks at national and international levels.

Figure 3. High-level strategic environmental and climate frameworks used to guide freight infrastructure planning, % of respondents



Calculate freight transport emissions

It is essential to compute the carbon footprint of a national freight transport system at an aggregate level and with appropriate disaggregation by transport mode and vehicle type. Ex-ante estimation of the possible impact of policy measures and ex-post monitoring of their impact requires accurate data collection. There is substantial literature on measuring freight emissions and international reporting standards (e.g. Smart Freight Centre, 2023 and ISO, 2023), though much of it applies more to micro-logistics than to macro-logistics.

Macro-level freight emission data can be collected in different ways, using different data sets and yielding markedly differing results (McKinnon and Piecyk, 2009). This problem is compounded in lower-income countries where systems of freight data collection are less well developed and statistics on key variables, particularly vehicle utilisation and fuel efficiency, are often lacking. The range of statistics required for comprehensive monitoring, analysis and modelling of road freight CO_2 trends is discussed in McKinnon (2010). It is important to supplement freight emissions data with statistics on key drivers of these emissions, which public policy instruments aim to manipulate. The relevant indices for these drivers are listed in Table 1.

Creating a national logistics observatory, such as that established in Chile (ITF, 2016), can significantly upgrade the collection of relevant data. Central Asian countries have been exhorted to share best practices in freight data collection and agree on statistical standards (ITF, 2019a). The EU could provide a model as its statistical directorate, Eurostat, issues directives to member states explaining how freight data must be collected and shared. The new European Commission's CountEmissionsEU regulation will go further and establish a common framework for measuring and reporting greenhouse gas emissions from transport (European Commission, 2023). The Central Asia Regional Economic Cooperation (CAREC) programme might consider undertaking a similar initiative.

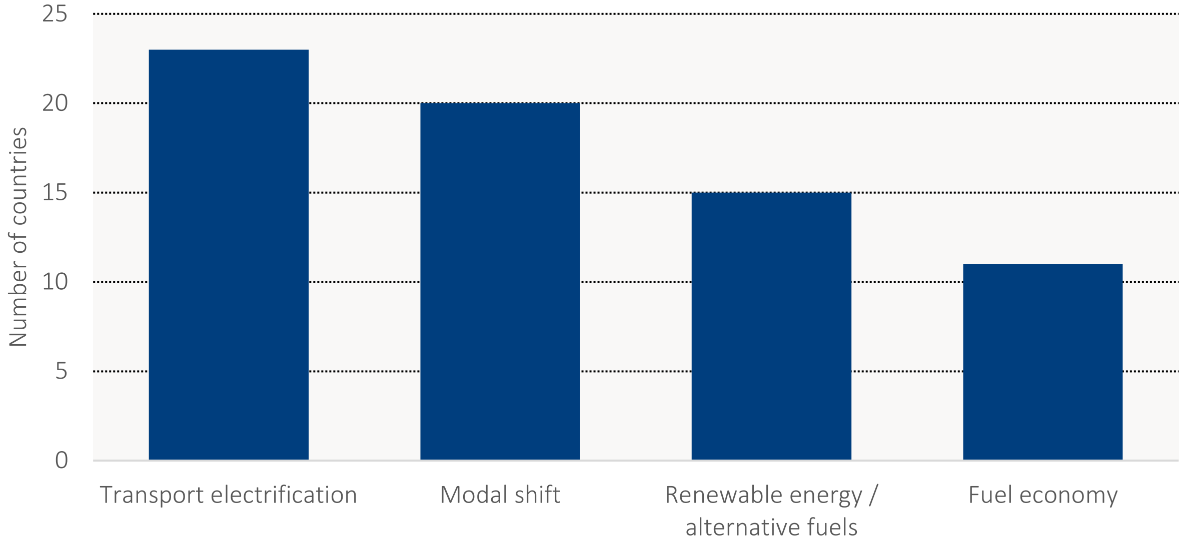
Table 1. Macro-level indices for key drivers of freight transport emissions

Driver of freight emissions	Relevant indices
Managing demand	Freight transport intensity (ratio of GDP to tonne-kilometres) Handling factor (ratio of tonnes lifted to production/consumption weight)
Freight modal shift	Freight modal split (tonne-kilometres by mode) Average carbon intensity by mode (gCO2 per tonne-kilometre)
Improving vehicle utilisation	Ratio of tonne-kilometres to vehicle-kilometres Share of truck-kilometres run empty Average weight-based lading factor
Raising energy efficiency	Average truck-kilometres and tonne-kilometres (for all modes) per unit of energy Average vehicle age Fuel economy standards for new/imported vehicles
Switching to low-carbon energy	Share of alternative low-carbon energy used by mode Tank-to-wheel (TTW) and well-to-wheel (WTW) average emissions intensity of non-fossil energy sources

Commit to carbon reduction targets

Very few countries have set freight decarbonisation targets. Some targets, such as those of the EU, have been set for transport as a whole with no differentiation between passenger and freight movements. Other targets have been set for specific carbon mitigation measures, but only for transport as a whole. Many Asian countries have set such targets, mainly for transport electrification and modal split (Gota and Huizenga, 2023) (Figure 4).

Figure 4. Numbers of Asian countries with targets for transport decarbonisation initiatives



Source: Asian Transport Outlook (2023).

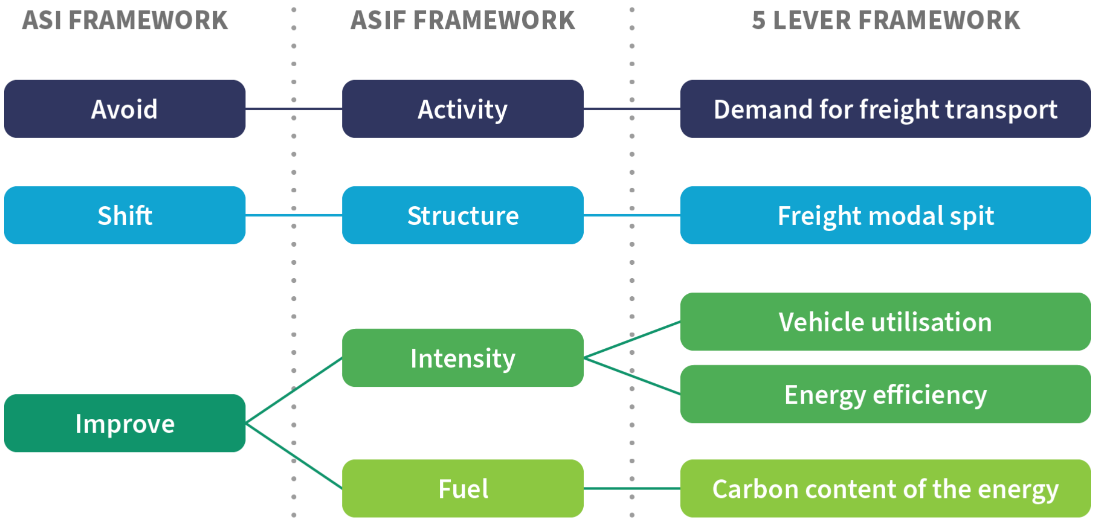
Most literature on setting carbon reduction targets for logistical activity is directed at businesses rather than governments (e.g. McKinnon and Piecyk, 2012; Science Based Targets Initiative, 2019). Many larger companies follow the guidance of the Science Based Targeting initiative (SBTi) and have had their targets SBTi-approved. There is no similar macro-logistics framework for deriving national freight emission targets. By default, these targets can be aligned with those set for the economy or country as a whole. Such top-down targets fail to take account of inter-sectoral differences in carbon mitigation costs and potential rates of carbon reduction.

In the case of freight transport, there are also marked intra-sectoral variations in abatement opportunities, costs and rates between, for example, vans undertaking last-mile deliveries and long-haul trucking. To ensure that carbon reduction targets are sensitive to these variations, it is advisable to base them on bottom-up analyses of what is feasible within budgetary, technical, infrastructural and market constraints over differing periods.

Consider policy options

Several policy toolkits have been compiled, listing a broad range of instruments that governments can use to decarbonise freight transport operations (e.g. GIZ, 2013; McKinnon, 2023). These initiatives can be classified into three (Avoid-Shift-Improve), four (Activity-Shift-Improve-Fuel) or five categories (5-lever framework) (Figure 5). Previous reports on Asian transport decarbonisation have adopted the ASI and ASIF frameworks (e.g. Gota and Huizenga, 2022). This paper will instead apply the five lever framework because it splits the “Improve” category into three variables (vehicle utilisation, energy efficiency and carbon content of the energy), each of which can be influenced separately by public policy measures and business practice.

Figure 5. Frameworks for classifying freight decarbonisation policy measures



Application of the five freight decarbonisation levers in Low- and Middle-Income Countries (LMICs) is discussed in McKinnon (2023). This report reviews recent trends, potential carbon savings, implementation barriers, and relevant public policy measures for each lever. The following section reviews the five levers and considers the amount of decarbonisation leverage they might exert on freight transport in Central and Southeast Asian countries.

Collaborate

For a national government, collaboration can take three main forms:

1. International collaboration: organisations such as ASEAN, UNESCAP, UNECE, CAREC, and ITF have promoted collaboration on transport sustainability among Asian countries. The Kuala Lumpur Transport Strategic Plan 2016-2025 (ASEAN, 2015), which includes a sustainability section, is an output of such collaboration. UNESCAP (2023) has also been promoting co-operative efforts to improve "freight connectivity" in ways that "contribute towards the decarbonisation of regional supply chains". There are numerous ways in which such regional collaboration can support the decarbonisation of freight transport, for example:
    - Shared investment in regional transport infrastructure.
    - Improved inter-operability of railway rolling stock.
    - Reduced delays for freight vehicles at international borders.
    - Liberalised cabotage arrangements for international carriers.
    - Sharing best practices in low-carbon logistics.
    - Joint research on low-carbon freight initiatives.
2. Collaboration with subnational administrations: regional and municipal authorities usually play a key role in implementing national policy but often have sufficient autonomy to develop their own transport decarbonisation strategies. This is of particular relevance to the decarbonisation of city

logistics. In the Recover scenario of ITF's 2021 Transport Outlook report, emissions from urban freight in Southeast Asian countries would almost double between 2015 and 2050 (ITF, 2021). Containing the growth of these emissions will require engagement with municipal authorities and agencies with local jurisdiction.

3. Stakeholder collaboration: in most Asian countries, ownership and control of logistics are in private hands, making it critical for governments to carefully manage their relationship with the private sector when trying to cut freight transport emissions. This is recognised by UNESCAP's Asia Pacific Green Deal for Business, whose declaration has "green infrastructure and logistics" as one of its five pillars and highlights the need to "mobilise public and private finance for green transformation" of logistics, among other activities. Given the high degree of fragmentation in road freight markets across Asia, much of the government interaction is likely to be with trade bodies representing the interests of small operators.

Cost carbon-reducing initiatives

Marginal abatement cost (MAC) analyses have become a standard means of comparing the carbon mitigation costs of decarbonisation initiatives across a range of socio-economic activities, including freight transport (e.g. Greening et al., 2019). Much of this analysis has been conducted on an ex-ante basis as the implementation of many freight policy measures has been at an early stage. There has also been a lack of ex-post evaluations of such measures, particularly in lower-income countries. One must exercise caution in transferring or extrapolating the published results of MAC analyses, either ex-ante or ex-post, between countries because differences in tax regimes, market structures, business practices and geography can strongly influence the relative cost-effectiveness of mitigation measures.

MAC analyses in the freight sector are also complicated by the difficulty of monetising wider costs and benefits, particularly in measures that are not narrowly targeted at the freight sector. For example, abolishing transport fuel subsidies, which were valued at USD 36 billion in Asian countries in 2021 (Gota and Huizenga, 2023), would exert strong upward pressure on the fuel and carbon efficiency of freight transport operations but would have wider socio-economic and political ramifications.

Many of Asia's lower-income countries are likely to be in the "low-hanging fruit" phase of freight decarbonisation when numerous opportunities exist to apply measures that cut both carbon emissions and costs (McKinnon, 2018). Identifying those measures with low or negative carbon mitigation costs should be a priority.

Choose an appropriate package of measures

In mapping the transport policy landscape in 15 Asian countries (including Indonesia, Kazakhstan, the Philippines and Thailand), the Asian Transport Outlook has recently reviewed 294 "transport policy and strategy documents". Seventy-five of those published between 2015 and 2023 relate to "climate", but only six relate to "logistics" (Gota and Huizenga, 2023). A total of 265 policy measures were identified but not split between passenger and freight transport, nor is an indication given of the packaging of measures into coherent strategies.

The packaging of decarbonisation measures can be challenging, given the range and diversity of policy options and the desire to combine mutually reinforcing measures over differing time scales. It is, nevertheless, worth integrating these measures into a programme or strategy, as the combined impact can be greater, and the business perception of government commitment to freight decarbonisation can be strengthened. As in the UK (Department for Transport, 2022), decarbonisation is often incorporated within a broader, multi-objective freight transport strategy.

Carbon offset

One of the outcomes of the Kyoto Protocol was the Clean Development Mechanism, which, in essence, was a government-level carbon offsetting scheme. This relates to a country's total carbon emissions and not specific activities. The relevance of this stage in the freight decarbonisation process to the government relates more to its role as a regulatory body, which could be extended into checking and accrediting carbon offsetting schemes employed by businesses in the freight transport sector.

It is common for logistics providers to use carbon offsetting as a means of reducing their reported annual emissions. This, however, can relieve market and regulatory pressure on the providers to properly decarbonise their transport operations. Carbon offsetting schemes have also been widely criticised for "over-crediting" carbon savings and other malpractices. A case can be made for government intervention in "voluntary carbon markets" to address these criticisms, as is already happening in countries such as Australia and Japan (Dawes et al., 2023).

Cut emissions: Implement the strategy

A government's freight decarbonisation strategy is typically hierarchical. To meet the high-level goal of achieving carbon neutral or net zero freight transport by a specified date, the overall strategy will define a general set of policy objectives and initiatives. Lower tiers in this strategic framework will set out carbon reduction strategies for specific transport modes, logistical geographies (urban, regional, national, etc.) and possibly commodity groups.

Broadly speaking, the freight decarbonisation toolkit comprises seven types of policy instruments (McKinnon, 2015a): financial incentives, taxes and charges, regulation, infrastructure and land use planning, market liberalisation, management of state enterprises in the freight/transport sector and advice/exhortation. They vary in their applicability at different levels in the strategic framework. The challenge is ensuring that the instruments are applied in ways that are not only horizontally and vertically compatible within the hierarchy but also mutually reinforcing, where possible.

Co-ordinating these policy measures is complicated by differences in implementation time and the time needed to deliver the expected carbon reductions. Several government agencies and industry organisations have used "roadmapping" to plan the phasing of policy developments in the longer-term decarbonisation of freight transport. The roadmap compiled by ALICE (2019), the European Technology Platform for Logistics, to reach "zero-emission logistics by 2050" in Europe sets a good example for Asian countries and regions. Roadmaps are typically based on estimates of the time it will take to get legislative approval, administrative and technological scale-up, and the level of market uptake and behavioural change required.

A further complication is the presence of second-order or rebound effects that can erode some of the anticipated carbon savings, which need to be factored into the modelling of the freight decarbonisation process (Lorca and Jamasb, 2017). At the heart of this process are "win-win" measures, such as improved vehicle loading and driver training, which simultaneously cut operating costs and emissions. By making freight transport cheaper, however, they can alter the trade-offs that companies make between transport costs, production, inventory and materials handling, thus increasing the distances goods are moved. Numerous attempts have been made to quantify the price elasticity of freight transport demand and, hence, the strength of any rebound effect (De Jong et al., 2010). As elasticity values are sensitive to a range of country- and location-specific variables, it is better to derive them locally than to extrapolate them internationally.

Calibrate the decarbonisation strategy

Ex-post evaluation of the impact of the policy initiatives, both individually and in combination, should help governments refine their freight decarbonisation strategies. It is more difficult for governments than businesses to recalibrate these strategies, partly because they are much more complex, extensive and long-term. The political process also often makes it difficult for policy makers to admit that measures have not delivered the intended carbon savings within the allocated budget and time scale.

It is usually desirable for the evaluation to be conducted externally by an independent body that can make judgments and offer recommendations on a non-partisan basis. Through networks such as ITF, ASEAN and CAREC, information about the effectiveness of decarbonisation policy initiatives can be shared between national governments and regional authorities. Even in countries with a long history of policy-making in sustainable transport, politicians, civil servants, and their advisers are still experimenting with freight decarbonisation measures and fine-tuning their implementation.

Freight decarbonisation levers

This section outlines the five decarbonisation levers, identifies macro-level metrics that can be used to monitor their impact, and considers how public policy can influence them.

Managing demand for freight movement

The lever equates to the Avoid option in the ASI framework. Of the transport-related carbon mitigation measures mentioned in the NDC statements of Asian countries, only 9% aim to reduce demand, and this primarily applies to personal travel (Gota and Huizenga, 2023). Given the gravity of the climate crisis, it can be argued that governments should reduce the demand for freight transport. In emerging markets, where economic development is understandably prioritised, such a policy is unlikely to gain much political support. Efforts to moderate the growth in freight transport demand may be seen as more acceptable.

However, because of the historically close correlation between GDP and tonne-kilometres growth rates, this option is often seen as potentially damaging to economic prospects. However, between 2010 and 2020 in Asian countries, freight activity and GDP growth trends decoupled negatively. GDP grew by 60% over this period, while freight tonne-kilometres increased by 45% (Asian Transport Outlook, 2022). Similar decoupling trends are already well-established in some developed countries. They are largely attributed to the service sector capturing an increasing share of national economic output and the offshoring of manufacturing to low-labour-cost countries. It appears that beyond a certain level of economic development, the rate at which the freight transport intensity of an economy increases slackens naturally without public policy intervention. The Asian Transport Outlook (2022), nevertheless, still projects a 4.5% annual growth in freight tonne-kilometres between 2015 and 2030.

Governments are naturally reluctant to accelerate this process of freight-GDP decoupling, though if they wished to do so, what policy instruments could they deploy? The relationship between GDP and freight tonne-kilometres growth, as reflected in an economy's changing freight transport intensity, is influenced primarily by two factors: the level of material consumption and the supply chain structure (McKinnon, 2023). The first of these factors determines the total amount of goods to be moved, which is outside the scope of this paper.

The second is a function of two variables: the average number of links in the supply chain, conventionally measured by the ratio of tonnes lifted to the weight of goods produced or consumed (known as the handling factor), and the average length of these links (known as the average length of haul). Research, mainly in European countries, suggests that the spatial dynamics of economic development exert a more substantial influence on the average length of a haul than on the handling factor, mainly as a result of businesses extending their market reach geographically and concentrating their production and logistics operations in fewer locations, both usually in response to improvements in transport infrastructure.

These spatial pressures are particularly strong as they yield substantial economic benefits and would be difficult for governments to restrain. In the unlikely event that they chose to do so as a freight decarbonisation measure, the carbon mitigation costs would be relatively high. Various fiscal, land-use planning and advisory measures can be used to tilt logistical cost trade-offs towards more decentralised patterns of production and warehousing (McKinnon, 2023). While this can reduce freight transport emissions, in most cases, the carbon savings would be exceeded by the additional emissions arising from more dispersed production and warehousing operations. Opportunities for constraining the rate of freight traffic growth beyond the extent to which it appears to be happening naturally in Asian countries, therefore, appear limited. One must exercise caution, however, in observing these trends at a continental level. Within both Central and Southeast Asia, trends in freight-GDP elasticity vary widely by country.

Although freight demand management is likely to offer little policy leverage on freight transport emissions in most of these countries, policy makers could gain a greater understanding of the process of freight traffic growth by monitoring several key indicators:

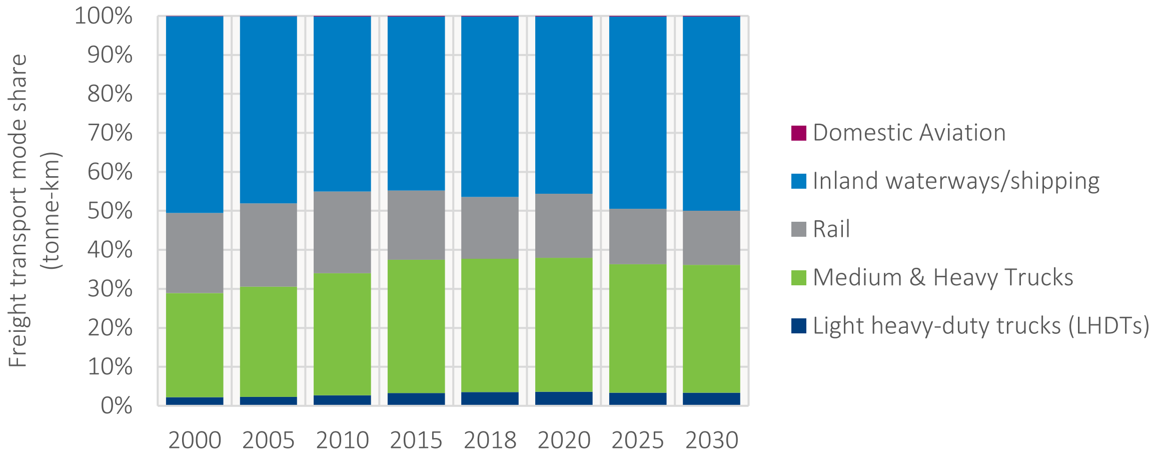
- Freight transport intensity: ratio of tonne-kilometres to GDP. This indicator relates the physical quantity of freight movement in a country to the monetary value of its national output. Monitoring this ratio over time shows the changing propensity of an economy to generate freight traffic as it expands and its structure evolves.
- Handling factor: ratio of tonnes lifted to the total weight of goods produced and imported or consumed and exported. Official freight surveys generally record the number of tonnes lifted onto a vehicle, wagon or vessel at the start of a journey. As each freight journey represents a link in a supply chain, dividing the aggregated tonnes-lifted figure by the total weight of goods transported yields a crude index of the complexity of a supply chain. This analysis is best conducted at the commodity level, where it can show how changes in industrial and supply chain structures affect the demand for freight movement.
- Average length of haul (ALH): average distance between the origins and destinations of consignments on individual trips. By indicating the average length of the links in a supply chain, this metric can show how the spatial extent of production and distribution systems is changing. As with the handling factor, the ALH is normally calculated at the commodity level. It also sheds light on the modal segmentation of a national freight market by distance range. This makes it a useful macro-level variable in assessments of the potential for freight modal shift.

Promoting freight modal shift

Modal split has been central to government efforts to improve the environmental sustainability of freight transport for decades. UNESCAP (2019) confirmed that this was the case for Southeast Asia when it declared that it had “long supported the countries in the region in progressing towards seamless and sustainable connectivity through better-integrated infrastructure across modes and a more balanced modal split which enables growing transport demand to be accommodated on proportionately less infrastructure, with materially better service to users and significant energy savings, in sum, integrated intermodal transport. This is basically the fundamental notion of connectivity that is sustainable…”.

Across most Asian countries, however, the road network has been increasing its share of freight tonne-kilometres, and cleaner, lower-carbon modes have declined in relative, and in some cases absolute, terms. At a continental level, the road share increased from 28% to 37% between 2000 and 2020, with the rail network being the main loser (Figure 6). Of fourteen Asian countries reviewed by the Asian Transport Outlook (2021), only two, Kyrgyzstan and Uzbekistan, increased their rail market share. In Asia, however, the dominant low-carbon freight mode is waterborne transport by inland waterway or short-sea shipping. It moves a larger share of tonne-kilometres than road, and the Asian Transport Outlook expects this share to rise from 45% in 2020 to 50% in 2030, mainly at the expense of rail.

Figure 6. Past and predicted freight modal split in Asian countries



Source: Gota and Huizenga (2022).

A quarter of the carbon mitigation measures for transport mentioned in Asian NDCs would promote a shift to lower carbon modes, but overall, "only a few countries in Asia have targets on shifting modal share and, where these targets exist, they are modest in nature" (Gota and Huizenga, 2023). Countries that currently send very little freight by rail, such as Thailand and Vietnam, see rail's contribution to the freight market remaining marginal in their national strategy documents, at under 4% of tonne-kilometres (Asian Transport Outlook, 2023).

At the other extreme, Kazakhstan, where the rail network handled 55% of freight traffic in 2018, there are plans to build 1 302 kilometres of new lines, electrify 522 kilometres of track and modernise 6 925 kilometres more, strengthening the country's role as a regional rail hub and a key node in one of the main trans-Asian rail corridors (UNECE, 2019). At a regional level, the CAREC Railway Strategy for the period 2017-2030 aims to construct 7 200 kilometres of new tracks within the network of Designated Rail Corridors (DRCs), closing infrastructural gaps (CAREC, 2017).

Across Central and Southeast Asian countries, it is not simply the potential for transferring freight to lower carbon modes that varies widely; the main modal recipient of this transfer also differs, with waterborne transport playing a more important role than in many other parts of the world. These variations make it essential to tailor modal split strategies to national freight markets.

Governments can, nevertheless, draw upon a standard policy tool kit when selecting a package of measures appropriate to local conditions (Aritua, 2019). They can also review evaluations of the relative effectiveness of these policy measures when applied elsewhere, as in the European Union (Takman and Gonzales-Aregali, 2021). As ITF (2022) acknowledges, however, "Pinpointing those policies that demonstrably alter the modal split in freight transport is difficult", and very few countries have been able to achieve a significant shift of freight to "non-road modes".

Questions are also being raised about the longer-term environmental desirability of displacing freight from trucking when its carbon intensity is predicted to drop sharply over the next 10-20 years as a result of fuel efficiency improvements and electrification, narrowing the emission gap per tonne-kilometre with alternative modes. Modal shift can still be justified, inter alia, on the grounds that rail and water-borne service will remain more energy-efficient. The rate at which modal carbon intensity values converge may also be relatively slow in Central and Southeast Asian countries, keeping modal shift as a critical policy option in the pursuit of short-to-medium-term carbon reduction targets. Nevertheless, UNESCAP (2021) was well-advised to explore the opportunities for decarbonising rail freight operations in Asia and thereby help rail maintain its carbon advantage.

The traditional range of macro-level metrics used to measure freight modal split can give a misleading impression of the current situation and the potential for modal shift. The most commonly used are the percentage of total tonne-kilometres and the percentage of total tonnes carried by each mode. As rail and waterborne services are more competitive over longer distances and normally have a larger share of the long-haul market, tonne-kilometres-based estimates are preferable and also reflect the level of freight transport activity more accurately.

The use of weight-based measures, however, introduces a bias against road freight, which generally carries products with both a lower physical density (ratio of weight to volume) and higher value density (ratio of value to weight) (Woodburn, 2007). This is significant because, in most countries, particularly those with large fossil fuel industries such as Kazakhstan and Mongolia, the energy transition will deprive rail and waterborne modes of coal and oil traffic, typically representing 30% or more of their freight tonnage. The substitution of lower-density, higher-value manufactured goods for this traffic, although yielding significant CO_2 reductions if captured from road, will not be adequately reflected in tonne-kilometres-based modal split trends. It would be beneficial, therefore, if traditional tonne-kilometres-based modal split statistics were supplemented by other volumetric indicators (such as share of cubic metres) or the proportions of truck-kilometres saved by transferring a particular commodity flow to rail or water. As volumetric freight data is very scarce or non-existent worldwide, the latter index is a more realistic option.

The environmental case for freight modal shift in Central and Southeast Asia could also be put on a firmer empirical base by compiling comparative modal emission factors specifically for these regions and their countries. In claiming that "greenhouse gas emissions per ton-kilometer for a freight train can be less than 30% of those of trucks", CAREC (2017) cites a general fact sheet from CER/UIC (2015) based mainly on European data. As modal emission factors are highly sensitive to variations in the energy and commodity mix, the nature of the infrastructure, and the age and capacity of the vehicles and rolling stock, they should be derived locally rather than extrapolated from other regions.

Improving utilisation of freight vehicles

A lack of data severely constrains macro-level analysis of the application of this freight decarbonisation lever. Almost all the available statistics relate to road freight movements, allowing operators of other freight transport modes to "escape similar scrutiny and censure, mainly because there is little hard evidence in the public domain of the under-utilisation of their capacity" (McKinnon, 2021). Ideally, governments should routinely collect data on freight utilisation indicators:

- Empty running: average proportion of vehicle-kilometres run empty.
- Weight-based lading factor: ratio of tonne-kilometres moved to available tonne-kilometres carrying capacity.
- Volume-based lading factor: ratio of cubic metre-kilometres moved to the available cubic metre-kilometres carrying capacity.
- Overloading: proportion of vehicle-kilometres travelled with a load over legal weight limits.

All four variables should be tracked for road freight operations, and the first three should be tracked for all modes. In practice, official utilisation data is only available for trucking in relatively few countries. Truck empty running data is available for European, North American and Latin American countries, though few countries elsewhere. Very few countries compile weight-based lading factor data, and none survey volumetric utilisation. Overloading data is patchy and tends to be confined to countries where the problem is acute, including Asian countries such as Indonesia and India.

The scarcity of statistics on capacity utilisation in the freight sector makes it very difficult to assess, at a national level, potential carbon savings from optimised loading and the effectiveness of any policy measures designed to raise load factors. Much of the research on this subject is based on surveys of small samples of transport operators or company case studies. The so-called "transport KPI" surveys undertaken in the UK between 1997 and 2010, primarily for benchmarking purposes, illustrated how "synchronised audits" of vehicle loading by weight and volume (as well as energy efficiency) could both generate macro-level data for environmental modelling and be an "effective catalyst for industry-wide discussion of the opportunities for improving transport efficiency" (McKinnon, 2009).

The available data provides hard evidence of widespread under- and over-utilisation of freight capacity in the road freight sector. Both carry a substantial carbon penalty. Under-loading results in more vehicle-kilometres than necessary being travelled to deliver a given quantity of freight with corresponding excesses in fuel consumption and emissions. While the over-loading of vehicles significantly reduces vehicle-kilometres, it requires the engine to operate much less fuel efficiently and damages the road pavement, which impairs the fuel efficiency of all traffic. Research in Indonesia, for example, found that annual CO_2 emissions per truck increased by between 22 and 54 tons for every 10% increase in overloading (Wahyudi et al., 2013).

In the absence of rigorous enforcement of truck weight restrictions and deterrent penalties, overloading is financially beneficial to the operator. On the other hand, underloading can be construed as evidence of a market failure, unnecessarily inflating transport costs. However, in managing transport as part of a logistics operation, companies are often prepared to incur these higher transport costs to save money on inventory, warehousing, and production or to generate more revenue by providing a faster delivery service. Just-in-time (JIT) replenishment, which is often blamed for low vehicle fill rates, illustrates such a cost trade-off. It is, nevertheless, only one of many causes of vehicle under-loading, some of which are less rational and more easily avoided (McKinnon, 2021, 2023). Even within wider logistical constraints, it is possible to cut empty running and raise vehicle load factors. The resulting carbon mitigation costs are low and, in many cases, negative; little capital investment is required, and the implementation time scales are relatively short.

Three developments in particular can improve the utilisation of freight vehicle capacity:

1. <u>Digitalisation of freight markets</u>: online trading of freight services using Big Data, AI, and machine learning offers improved matching of loads with available capacity. The Indonesian online platform Waresix provides a good illustration of this capability.

2. <u>Supply chain collaboration</u>: several European studies have demonstrated the asset utilisation and carbon reduction benefits of supply chain partners co-ordinating their logistics (Cruijssens, 2020; Jacobs, 2014). Similar collaborative initiatives are developing across Asia, such as the Thailand Supply Chain Network, promoting "joint resources utilisation".

3. <u>Move to higher capacity vehicles</u>: where road infrastructure permits, transitioning from rigid to articulated vehicles improves utilisation by permitting greater load consolidation (within legal weight limits) and decoupling loading from delivery in "drop-and-hook" operations. Further relaxation of truck size and weight limits in "high-capacity transport" (ITF, 2019b) has been shown to offer significant CO_2 reduction after allowance for "reverse modal shift".

High-capacity transport requires a regulatory change to truck weights and dimensions, and in some countries, quantitative licensing laws need to be revised or repealed to give operators the freedom to backload and share vehicles. Otherwise, most vehicle utilisation initiatives are industry-led, sometimes with the support of government-sponsored advisory schemes. For example, Green Freight Asia, headquartered in Singapore, is a “non-profit association of industry players, which collaborates with industry companies, NGOs, and governments to improve energy efficiency, fuel efficiency, reduce CO_2 emissions, and to lower operational costs across the entire supply chain”.

Raising energy efficiency

There is a dearth of macro-level statistics on the energy efficiency of freight movements within and between Asian countries. More data is available on fuel consumption by cars and buses than by trucks. There has also been a stronger policy focus on the fuel economy of passenger vehicles relative to freight vehicles, despite the fact that in Asia-Pacific countries in 2018, trucks were responsible for a higher proportion of transport CO_2 emissions (35%) than cars (27%) (Asian Transport Outlook, 2023). According to the Asian Transport Outlook, eleven Asian countries have set fuel economy targets for road vehicles, but these relate mainly to light-duty vehicles (LDVs).

Within the region, only Japan and China have set fuel economy standards for new trucks so far. However, this has wider regional significance as both countries export new trucks to neighbouring countries. It is worth noting that the equivalent standards for new trucks introduced by the EU in 2019 are defined in terms of carbon efficiency rather than just fuel economy, incorporating the transition to lower carbon energy within the standard.

While raising the fuel efficiency standard for new trucks is an important decarbonisation initiative, it has a relatively small near-term impact as the vehicle replacement rate in the lower-income countries of Central and Southeast Asia is slow. Moreover, much of the vehicle replacement is with imports of used vehicles, which, though younger, are significantly less energy efficient than the latest generation of new trucks. As a result, improvements to the average fuel efficiency of road freight transport are constrained by the age and technical performance of the vehicle fleet. Vehicle maintenance levels and the availability of spare parts tend to be inferior to those in Europe and North America, causing the fuel efficiency of new and used trucks to degrade more rapidly.

Within these constraints, however, there are still many ways in which road carriers can improve fuel efficiency in the short to medium term (McKinnon, 2015b). Broadly speaking, they fall into three categories:

1. <u>Driver-related</u>: training drivers to operate trucks in a more fuel-efficient manner, monitoring their subsequent driving behaviour using onboard telematics, and providing further guidance where necessary, is one of the most cost-effective means of decarbonising freight transport. Nineteen studies reviewed by Alam and McNabola (2014) “reported potential reductions in fuel consumption and CO_2 emissions ranging from 5% to 40% across various jurisdictions and initiatives”.

2. <u>Vehicle-related</u>: an existing truck can be retrofitted with aerodynamic profiling, anti-idling devices, and low rolling resistance tyres, and be more rigorously maintained, each action offering a cumulative reduction of several percent of total fuel consumption.

3. Operations-related: reducing maximum vehicle speed, rescheduling deliveries to off-peak periods, and re-routing vehicles around congestion bottlenecks, where possible, can all yield significant fuel savings.

Governments can use a series of policy instruments to promote the uptake of these energy-saving measures. Arguably, the most effective solution is to phase out fossil fuel subsidies in countries where they still exist and gradually replace them with fuel taxes. Over the past decade, this has been happening across Asian countries, ranging from Indonesia to Uzbekistan. Governments can also subsidise driver training and vehicle retrofitting programmes and set up advisory schemes for freight operators. The energy efficiency of road haulage can also be enhanced by greater spending on road maintenance, congestion relief, and the enforcement of vehicle weight and speed restrictions.

Effective formulation, monitoring and evaluation of these policies requires much more energy data than is currently available. Governments should be tracking the following metrics at a macro level:

- Average fuel efficiency for the existing medium- and heavy-duty vehicles fleet, generally expressed as litres consumed per 100 kilometres.
- Average age and fuel economy or emission standards of imported used vehicles.
- Age profile of the truck fleet: vehicle registration schemes can generate this data.
- Vehicle replacement rate: ratio of total truck numbers to annual truck sales.
- Proportion of truck drivers trained in eco-driving methods.

This energy efficiency data can be combined with the vehicle utilisation data to analyse trends in freight movement's energy and carbon intensity, expressed as energy use and carbon emissions per tonne-kilometre. In integrating these metrics, allowance should be made for the inverse relationship between vehicle weight and fuel efficiency. While raising the load factor increases fuel consumption, the additional fuel used per tonne is relatively small (Coyle, 2007). Consequently, there is a net reduction in carbon intensity.

Transitioning to lower carbon energy

Unlike the other four levers that can be largely applied within the transport and logistics sector, this lever depends heavily on external factors in the energy sector. The availability of low-carbon fuels, their well-to-wheel emissions, the carbon intensity of electricity generation, and the ability of national electricity grids to distribute low-carbon energy to recharging stations and transport networks are all critical to a low-carbon energy transition in the freight sector.

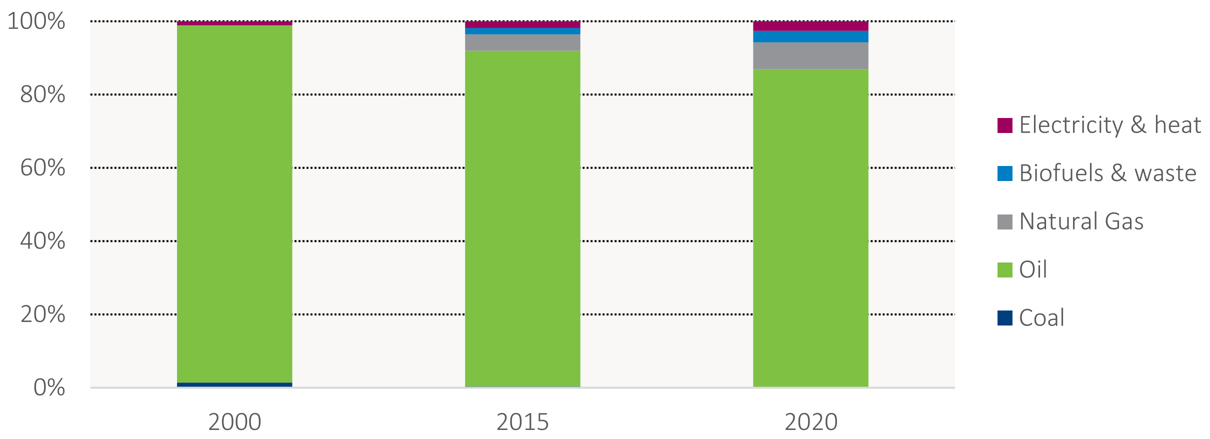
Within Central and Southeast Asia, there are major differences between countries in the rate at which their energy systems are decarbonising and the nature of the process. The rate is strongly influenced by a country's fossil fuel endowment and its potential to generate electricity from solar, wind, hydro and nuclear power (Konnor et al., 2023).

The transition to low-carbon energy in the freight transport sector can be divided into three phases, each presenting analytical challenges:

1. Use of less carbon-intensive fossil fuels.

This phase mainly involves a switch from diesel and petrol to liquid natural gas (LNG). Across the Asia Pacific transport sector as a whole, natural gas has become the main alternative to liquid fossil fuels, but in 2020 still accounted for only around 7% of its total energy consumption (Asian Transport Outlook, 2023) (Figure 7). Its use has been concentrated in light-duty vehicles, though the use of LNG to power trucks is projected to increase in the APAC region over the next few years (Exactitude Consultancy, 2023). This would be consistent with more general policies in countries such as Thailand and the Philippines to use imported LNG as a key driver of decarbonisation (Nitta and Shiga, 2023).

Figure 7. Proportion of transport energy in the APAC region from different sources



Source: Asian Transport Outlook (2023).

The net GHG savings from a switch to gas in the road freight sector is, nevertheless, likely to be small or non-existent, primarily for the following reasons:

- Tailpipe GHG emissions from LNG trucks with spark ignition engines, the majority of such vehicles, are only 3-5% lower than those from diesel trucks (Cornelis, 2019).
- Significant amounts of natural gas (i.e. methane) typically leak from the LNG supply system and often from the vehicles using it (Camuzeaux et al., 2015). Since methane has a high global warming potential (86 times greater than that of CO_2 over 20 years), these fugitive emissions can offset much, if not all, of the CO_2 saved by switching from diesel or petrol. Cornelis (2019), for example, found that "well-to-tank emissions from the production and transport of gas are on average 26% higher in the EU than fossil diesel". It is essential, therefore, that emission comparisons with LNG are conducted on a well-to-wheel basis. Such analysis has cast serious doubt on the carbon benefit of dual-fuel vehicles, capable of burning both LNG and diesel to extend their range while the gas supply network develops (Stettler et al., 2016).
- Gas-powered vehicles have substantially higher capital costs and require significant investment in refuelling networks, though maintenance costs are generally lower.

The main environmental justification for using LNG in road freight transport is to improve air quality. It can offer 80% reductions in nitrous oxide and particulate matter. Its carbon impacts are, at best, marginally positive and often negative.

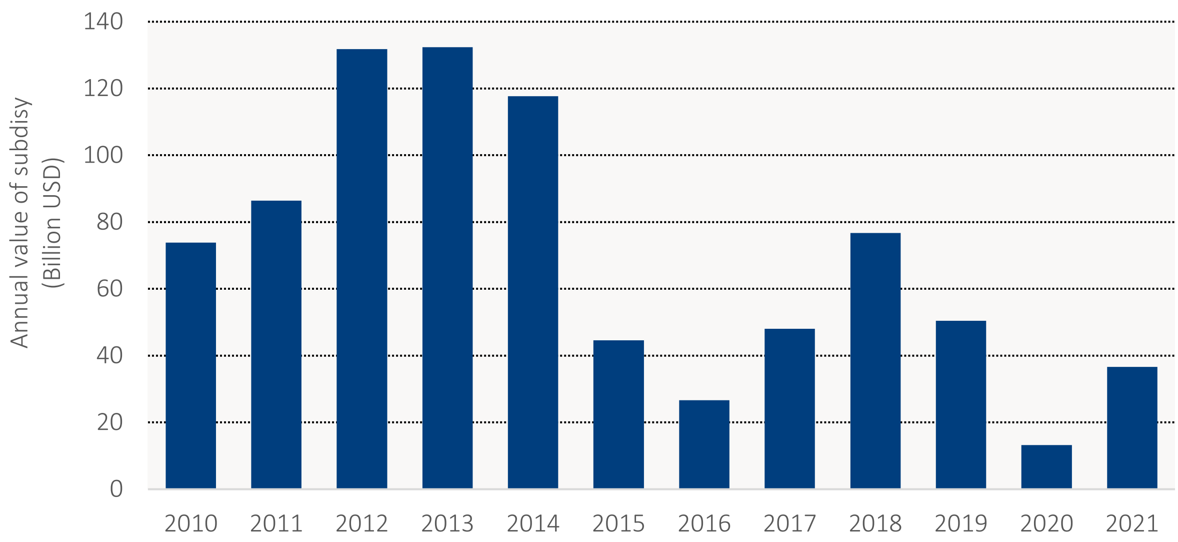
2. Use of biofuels.

This second phase is at a very early stage, with only around 3% of all transport energy in Asian countries coming from biofuels in 2020, mainly blended with fossil diesel or petrol. The highest uptake has been among the large producers of the biomass required for these fuels, such as Indonesia and Malaysia.

Indonesia has mandated fuel suppliers to blend 20% of biodiesel with diesel and is trialling a 30% mix (IEA, 2019). In many countries, however, freight demand for biofuels is constrained by their relatively high cost per litre, concern about engine wear, particularly in older fleets, and a lack of supply of consistent quality and environmental sustainability.

The first of these constraints is compounded by governments subsidising the fossil fuels used in the transport sectors of Asian countries. Although subsidies have been reducing overall (Figure 8), they can still significantly skew freight energy use towards fossil fuels in Asian countries (Asian Transport Outlook, 2023; IEA 2022). Concerns about the well-to-wheel sustainability of biofuels also deter their use and, as with LNG, make it essential to conduct full life-cycle analyses to confirm that they offer net GHG savings. In some parts of North America, low-carbon fuel standards (LCFS) have been introduced to compel *"fuel suppliers to progressively decrease the average GHG intensity of their fuels on a life-cycle basis"*, and this has proved quite an effective policy tool (Axsen and Wolinetz, 2023). There is no evidence of similar schemes being implemented in Asian countries to date.

Figure 8. Annual value of transport fossil fuel subsidies in the Asia Pacific Region



Source: Asian Transport Outlook (2023); IEA (2022).

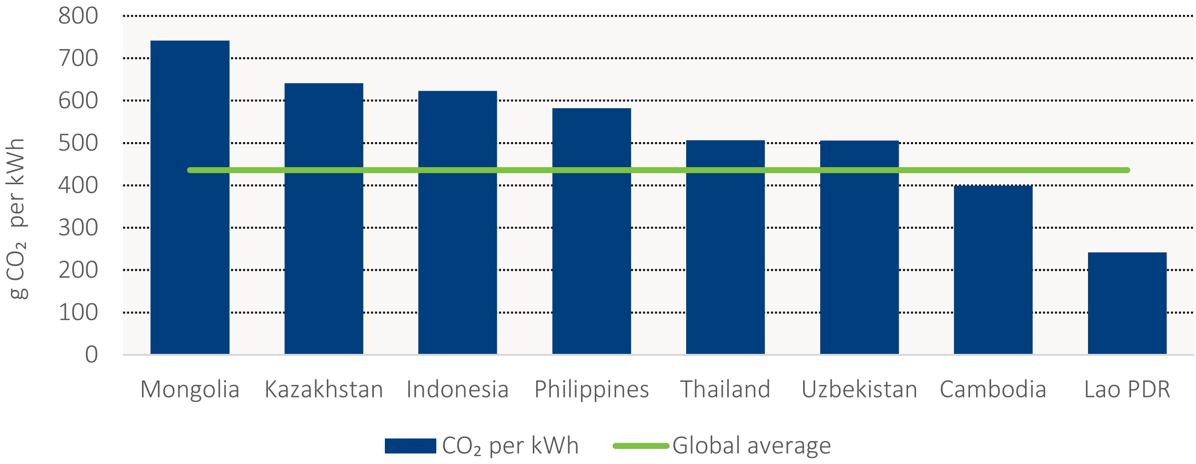
In the freight transport sector, biofuel has been widely seen as a transitional energy source offering interim carbon reductions while gradual repowering with green electricity is underway. As this latter transformation is expected to be much longer in Central and Southeast Asia than in Europe or North America, this transitional phase will be relatively long, raising questions about the available supply of environmentally sustainable biomass and the risk of transport demand for biofuels constraining future food production for an expanding Asian population.

3. Repowering freight vehicles with low-carbon electricity.

This is the path that ultimately leads to zero-emission freight transport, but it will only reach this destination if the following critical conditions are satisfied:

- The Asian electricity supply is decarbonised. As Figure 9 shows, the carbon intensity of electricity generated by some of Central and Southeast Asia's larger economies is currently above the global average and will have to drop sharply to achieve transport decarbonisation.

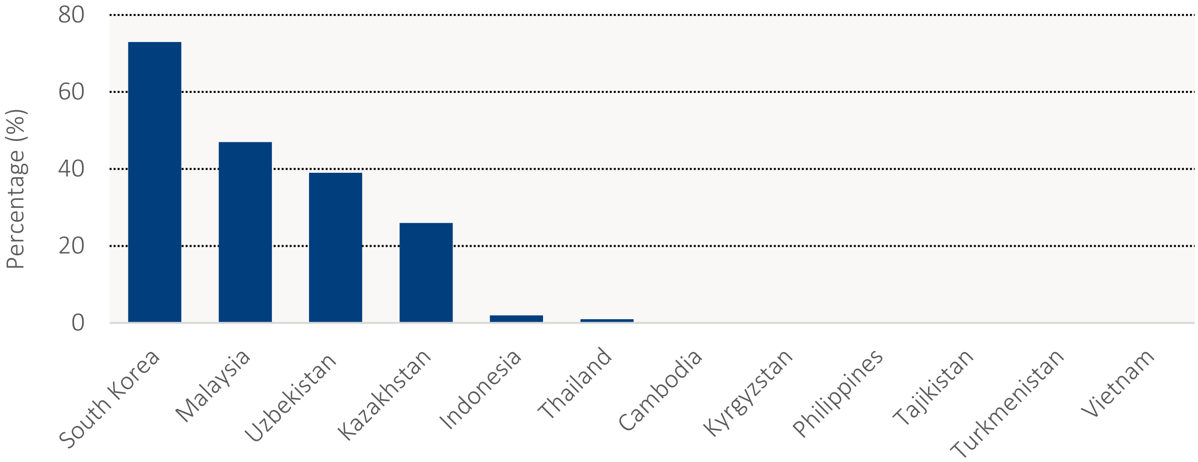
Figure 9. Average carbon intensity of electricity generation in Asian countries 2021



Source: Wiatros-Motyka (2023).

- An adequate supply of low- or zero-carbon electricity is generated to satisfy the demands of freight transport and logistics in a very competitive future market for green electricity. In Europe and the United States, where the electrification of trucking is at a more advanced stage than in Central or Southeast Asia, lack of grid capacity has become a major bottleneck (Konstantinous and Gkritz, 2023; Shoman et al., 2023). Asian countries may learn from the European and North American experiences related to this problem.
- Investment in the distribution of green electricity to battery charging stations, overhead catenaries for rail, and possibly road, networks and electrolysers for the production of green hydrogen, which may have a limited role in decarbonising long-distance, heavy haulage by road and rail. Fifty-four percent of Asia's total rail network is already electrified (Gota and Huizenga, 2023), though this percentage varies widely within Central and Southeast Asia (Figure 10) (UNESCAP, 2021).

Figure 10. Percentage of national rail network electrification in Central and Southeast Asia



Source: UIC (2019).

- Transformation of freight fleets across all modes to allow them to be powered by electricity directly or indirectly with batteries or fuel cells. In the case of road freight, this process is likely to progress more rapidly in Asian countries with an indigenous truck manufacturing industry, such as Thailand, and much more slowly in those where road haulage sectors are financially under-capitalised and heavily dependent on the import of used trucks. The import cycle for electric trucks is likely to be significantly longer than that of ICE trucks and complicated by the need to recondition or replace batteries for a second vehicle life.

Punte (2023) has identified nine stakeholder groups and mapped their required interactions within an "actionable framework" for the transition to electrified road freight. This illustrates the complexity of the process. The challenge for national governments will be co-ordinating the development of transport and energy infrastructures with the manufacture and importation of new low-carbon trucks and operators' fleet replacement cycles, which are relatively long in lower-income Asian countries.

As the pace of transitioning Asian road and rail freight operations to low-carbon energy is likely to be relatively slow and potentially too slow to meet 2030 and 2050 carbon reduction targets, governments in Central and Southeast Asia would be well advised to place greater emphasis on the previous four decarbonisation levers in the short-to-medium term, thereby minimising the total amount of freight transport energy that will eventually have to be "de-fossilised".

Key macro-level variables to track this energy transition include:

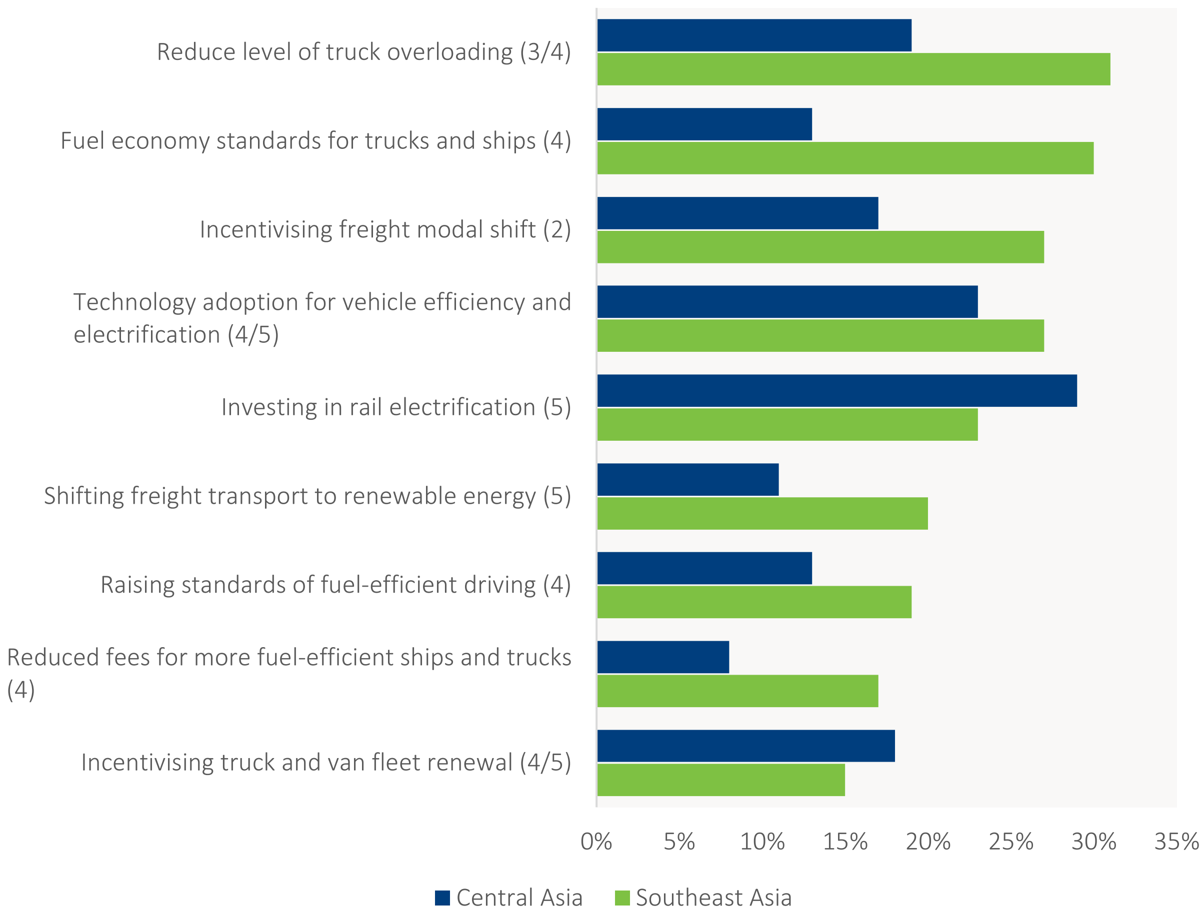
- The evolution in energy mix in road and rail freight operations.
- The average carbon intensity of grid electricity.
- The proportion of tonne-kilometres moved by electrically-powered trucks and locomotives.
- The availability of sustainable biofuel for road freight operations.
- The average CO_2 intensity of road freight biofuels on a well-to-wheel basis.

Including decarbonisation levers in sustainable freight strategies

A survey of officials in governmental organisations in Central and Southeast Asian countries for the ITF-SIPA project enquired about the current representation of sustainability measures in freight transport strategies. Figure 11 shows the level of adoption of nine policy initiatives contributing to the decarbonisation of freight transport in the two regions. The numbers in brackets indicate which of the five decarbonisation levers would be affected by the initiative. Much of the policy focuses on energy-related levers (4 and 5). Across all but two of the nine initiatives, the percentage responses were significantly higher from the Southeast Asian sample, with the widest gaps between the two regions including policies on truck overloading, freight modal shift and fuel economy standards for trucks and ships. Rail electrification was a stronger priority in Central Asia.

It is encouraging that, according to the survey, a range of mutually reinforcing policy measures are being deployed to decarbonise freight transport. However, a cause for concern is that the adoption rates in both regions are relatively low, at under 30% for almost all measures.

Figure 11. Sustainability and decarbonisation policies included in organisations' freight transport strategies, % of respondents



Measuring and reducing infrastructure-related emissions

As discussed in the first section, it is particularly important to adopt a life-cycle approach to decarbonising freight transport in emerging markets where transport infrastructure is rapidly developing and currently inducing structural changes to logistical systems. Infrastructural investment has a crucial role to play in the application of each of the five freight decarbonisation levers:

1. Managing demand: by improving connectivity and reducing transit times and transport costs, upgraded infrastructure promotes spatial logistics trends that generate higher volumes of freight movement, making it harder to moderate the growth in demand.
2. Freight modal split: the allocation of infrastructural investment between transport modes determines their relative levels of network connectivity, accessibility and transit time, which in turn affects modal competitiveness.
3. Vehicle utilisation: infrastructural constraints on the maximum weights and dimensions of trucks and freight trains' length and axle weights influence the extent to which loads can be consolidated.
4. Energy efficiency: the alignment and gradients of roads and railway lines, road pavement quality, and congestion levels on road and rail networks strongly influence vehicle and locomotive fuel efficiency.
5. Energy transition: transforming transport infrastructure to accommodate the new generation of low-carbon vehicles requires heavy investment in electrification, battery charging facilities, grid capacity and refuelling stations.

Life cycle assessments of transport infrastructure typically include various environmental externalities. Numerous frameworks and tools now exist to assess the environmental sustainability of road projects against these criteria (Hoxha et al., 2021; Suprayoga et al., 2019). The focus here will be on GHG emissions. Incorporating infrastructure-related GHG emissions within freight transport's carbon footprint raises the following issues:

(a) Delimiting the boundary around infrastructure-related emissions and classifying them by activity.

Liu et al. (2022) reviewed the scoping of life-cycle CO_2 emissions from road construction in twenty-two studies and found significant differences. To be comprehensive, the emission boundary should encompass at least five activities, the first three occurring during the construction phase and the other two subsequently:

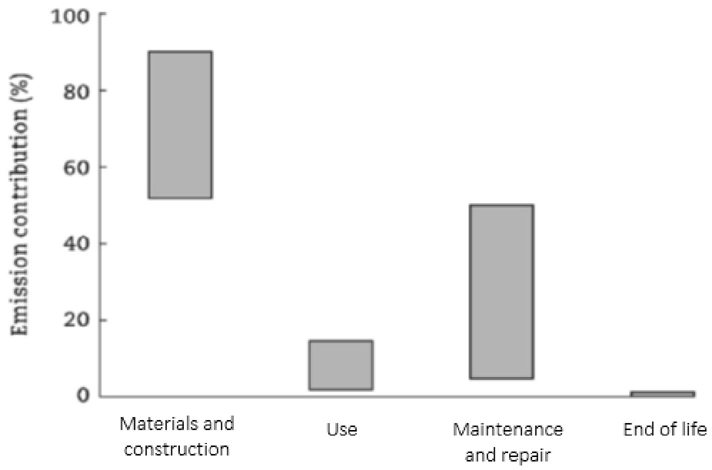
- Earthworks: involving land clearance, any associated deforestation, demolition of existing buildings, and excavation of tunnels and cuttings.
- Nature and sourcing of materials: the embodied emissions of materials such as aggregates, concrete, steel, and asphalt, including the scope 3 emissions from their upstream supply chains.
- Construction operations: including emissions from the operation of machinery, materials used during their preparation and installation, and facilities for the construction workforce.

- Maintenance and repair: producing a similar range of emissions to the construction phase but spread over many years, including additional emissions from traffic that is delayed or diverted during the work.
- Operations: direct emissions from managing the asset rather than from vehicles using it. These emissions come from de-icing, snow clearance, accident recovery, lighting, signalling, security, etc.

A few LCA studies include an "end-of-life" phase in the assessment during which the infrastructure is dismantled, waste material is disposed of or recycled, and the landscape is restored. As this is a rare occurrence within the typical timeframe of freight decarbonisation studies, it is excluded from the classification above. Some studies subsume earthworks within the construction category, though there is analytical merit in keeping them separate.

The relative proportions of emissions coming from these activities over the life of the asset vary widely with respect to the type of infrastructure, the topography of the land, climatic tolerances and proximity to the sources of construction material. When these real-world differences are overlain by methodological inconsistencies in the collection and analysis of emission data, the resulting variation in the estimated proportions of emissions from various activities can be wide. Figure 12 shows the range of emission contributions for road infrastructure reported in six studies reviewed by Lui et al. (2022).

Figure 12. Range of estimates for the shares of road infrastructure-related emissions at different life-cycle phases: review of six studies



Source: Liu et al. (2022).

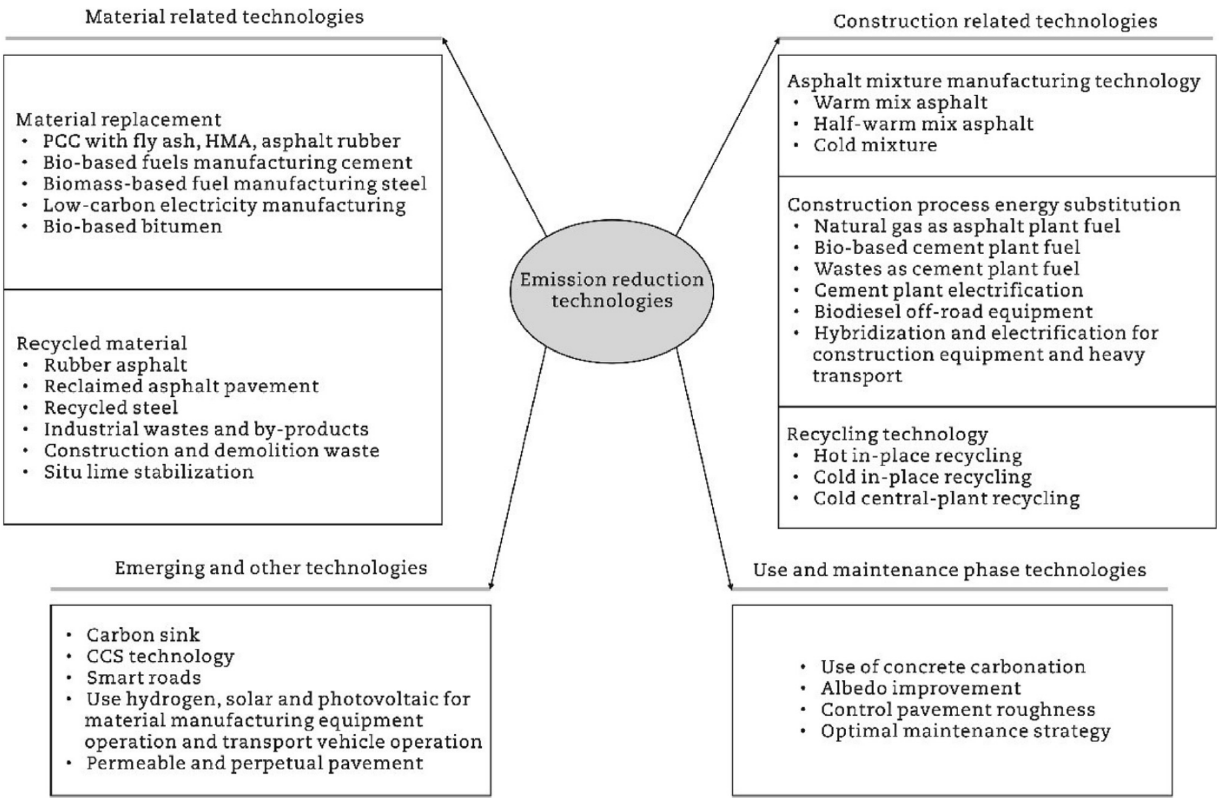
Despite this variability, it is clear that the emissions embodied in the infrastructure during construction dominate the life cycle assessment, followed by emissions from maintenance and repair during the asset's life. There is an inter-relationship between the categories of emissions. Building a road to a higher standard initially can be more carbon intensive but reduce the subsequent need for maintenance and repair.

A similar classification of GHG emission categories is generally adopted in rail infrastructure LCA studies, but again, the methodology has significant differences. UIC (2016) applied five methodologies to calculate the infrastructure CO_2 emissions from a single-track rail line in Sweden and found estimates ranging from 10 151 to 25 911 tonnes per annum. A review of 22 papers with 57 case studies by Olugbenga et al. (2019) concluded that the "large variation in scope, functional unit, boundaries and inventory methods make it challenging to compare the case studies". They were able, however, to estimate the average embodied emissions in a freight railway line "at-grade" (i.e. on the level) at around 700 tonnes of CO_2e per kilometre. This figure can rise sharply on sections of lines with bridges and tunnels. For comparative purposes, Lekosh et al. (2022) estimated the embodied CO_2e emissions per kilometre for a dual-3 lane highway to be 2 650 tonnes, for a dual-2 lane to be 2 014 tonnes and for a single-2 lane carriageway to be 880 tonnes.

(b) What are the main levers for reducing infrastructure emissions?

Opportunities for cutting GHG emissions exist at each stage in the infrastructural life cycle. Figure 13 lists the main emission reduction technologies at each stage.

Figure 13. Range of carbon-abatement technologies for road infrastructure



Source: Liu et al. (2022).

The core materials used to construct transport infrastructure, i.e. cement, concrete, asphalt and steel, are all hard to decarbonise, though the use of recycled waste products has been shown to significantly reduce embodied carbon emissions in asphalt road surfaces (Yaro et al., 2023). A UK study has found that the "use of low-carbon alternatives and secondary (reclaimed) materials could reduce the whole life carbon of new roads by 2-12% over the asset's life period of 40 years (2020-2060)" (Lokesh et al., 2022).

Material- and process-related emission reductions can be achieved both at the construction and maintenance phases. They can be supplemented when a road is being maintained or upgraded by adopting traffic management schemes that minimise emissions. For example, Hanson and Noland (2015) show how intermittent, rather than complete, closure of a road during a construction project can reduce the additional CO_2 emissions from traffic disruptions by 19%.

(c) <u>How should infrastructure-related emissions be combined with operational emissions in an integrated life-cycle assessment of freight's overall GHG emissions?</u>

This involves two allocation exercises: dividing the infrastructural life cycle emissions between freight and passenger flows using the same road or railway line and splitting the freight share of these emissions between traffic units.

- <u>Freight-passenger split.</u> As trucks and freight trains are much heavier than cars and buses, they require road pavements and rail tracks to be built to higher load-bearing standards. They can also be responsible for a higher proportion of the subsequent maintenance work. Freight trains also travel more slowly than passenger trains, so refuge sidings are needed at intervals along the track to allow passenger trains to pass. GHG emissions associated with these refuges' construction are typically assigned to freight traffic. Overall, freight flows on both road and rail networks are apportioned a higher share of the construction and maintenance budget. The financial allocation could be used as a surrogate for freight's share of GHG emissions in the absence of more specific analyses of the additional embodied emissions attributable to freight.
- <u>Distribution across freight traffic units.</u> Once freight has been allocated a share of total embodied emissions for the design life of the road or railway line, this total can be divided by the number of trucks, freight trains or rail wagons traversing it. For example, if a kilometre of highway has embodied emissions of 1 000 tonnes of CO_2e over a 40-year service life (slightly above the 33-year average used in 97 studies reviewed by Hoxha et al. (2021)) and a third of those emissions were attributable to trucks, then 8.3 tonnes of CO_2e would be distributed across of all trips made by trucks in a year. Assuming an average of 1 000 truck trips per day on the road over 365 days, each trip would be allocated 22.6g of CO_2e per kilometre. To put this hypothetical figure into perspective, the average carbon intensity of transporting freight in an articulated truck is approximately 80g CO_2 per tonne-kilometre (DBEIS/DEFRA, 2022). If the truck carried an average load of 20 tonnes, the infrastructure-related CO_2 would represent approximately 1.4% of the CO_2e emitted by this road freight movement. A more granular analysis could differentiate the allocation of infrastructure-related emissions by vehicle weight class and utilisation. For policy formulation purposes, however, data disaggregation to a vehicle level may not be required. Knowledge of the total amount of infrastructural GHG likely to be attributable to freight over the life of a road or rail project may suffice.

(d) <u>To what extent is the inclusion of infrastructure-related emissions likely to influence freight decarbonisation policies?</u>

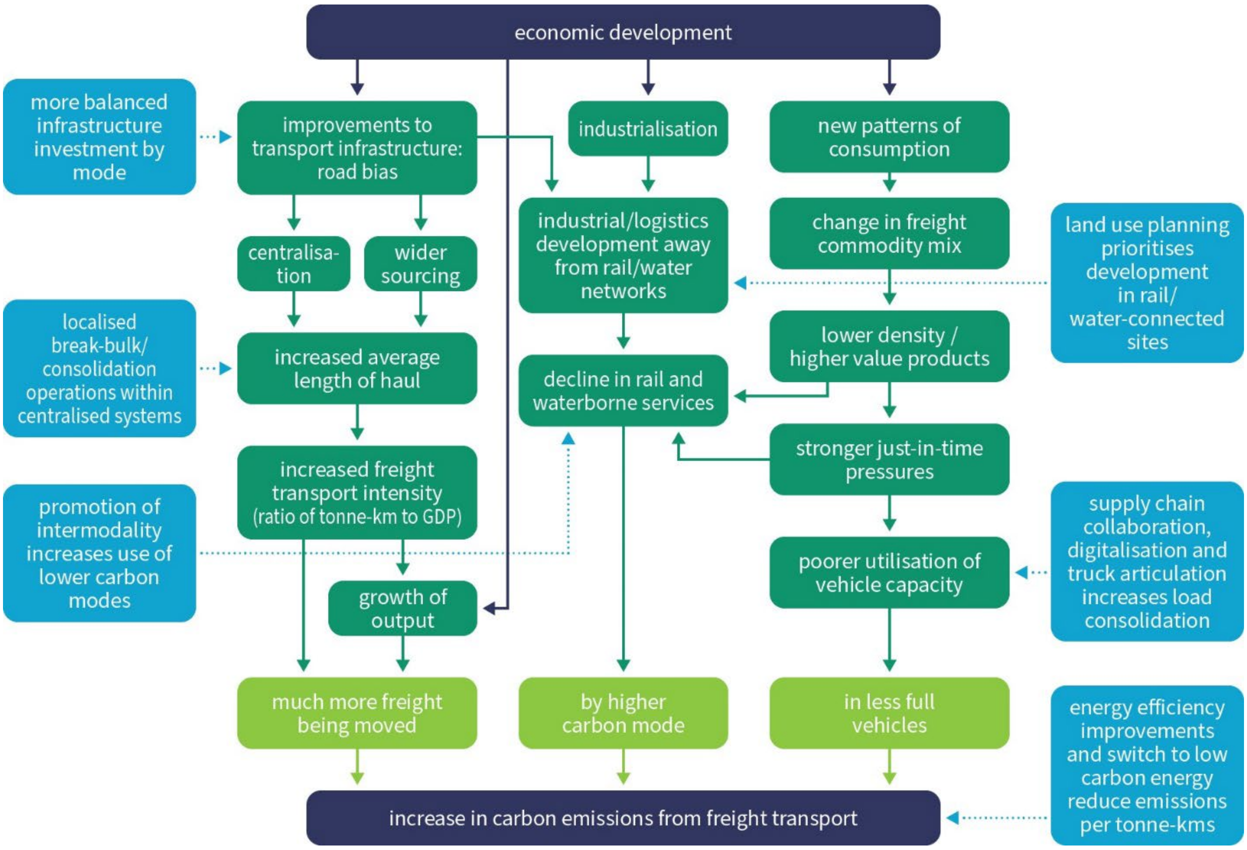
One policy that may be sensitive to the inclusion of these emissions is shifting freight from road to rail. Ambitious targets to achieve a significant realignment of logistics systems from road to rail would, in many countries, require investment in new infrastructural capacity. In deciding whether such an investment would be justifiable in carbon terms, a government could undertake a "carbon payback" calculation. This divides the GHG emissions released during the construction phase of the new rail capacity by the likely annual savings in GHG emissions from the freight modal shift to get an indication of how long it would take for the accumulated savings to exceed the initial construction-related emissions. UIC (2016) estimated this payback period to be around 12 years for a dedicated freight rail line, though this figure is likely to be subject to wide variation. UIC, which represents and promotes rail interests, is confident that "adding railways' infrastructure carbon content to all the eco-calculation tools is not having a significant impact on the overall carbon competitiveness of the railway sector compared with the other modes of transport".

Conclusions

The introduction posed a critical question about freight transport sustainability for countries in Central and Southeast Asia, namely, to what extent it might be possible for them to follow a lower-carbon path of logistics development than that pursued by the high-income countries of Europe and North America over the past 50 to 60 years. This conclusion offers a possible answer to the question.

The internal section of Figure 14 maps the typical pathways to high-carbon logistics in countries where economic development and the upgrading of transport infrastructure trigger a series of spatial and operational processes that increase the energy intensity of freight transport. The shaded boxes around the periphery of the diagram contain initiatives which can mitigate the effect of these processes on energy consumption and CO_2 emissions.

Figure 14. Typical relationship between economic development and freight transport emissions and examples of mitigating initiatives



Source: adapted from McKinnon (2018).

As these core processes generate substantial economic benefits from economies of scale, lower inventory, greater productivity and higher sales, they are difficult to constrain or modify. Their detrimental effects on the environment can, however, be significantly reduced by the implementation of the six mitigation measures at an early stage in the transformation of a country's logistical system that accompanies higher levels of economic growth:

- Investing in multi-modal transport infrastructure: distributing this investment more evenly by transport mode can avoid long-term over-dependence on road haulage.
- Preserving or creating dispersed networks of break-bulk and consolidation points: within centralised systems of warehousing and production, these networks can help businesses adjust the nature and capacity of their delivery operations to local conditions, improving their efficiency and reducing their carbon intensity.
- Land use planning policy prioritising development on rail- and water-adjacent sites: clustering factories and warehouses in locations with easy access to lower-carbon transport modes.
- Promoting intermodality: for the numerous industrial and logistical premises established in solely road-accessible locations, intermodal infrastructure and services will be required for a "carbon-friendly" modal split.
- Pursuing load consolidation strategies: within time-sensitive, JIT-driven production and distribution systems, supply chain collaboration, digitalisation, and the "articulation" of much of the truck fleet (permitting "drop-and-hook" operation) can improve capacity utilisation.
- Transitioning to more energy-efficient, low-carbon vehicles: this can proceed independently of the core processes in Figure 11, reducing CO_2 emissions per tonne-kilometre over a period when these processes are driving rapid growth in total tonne-kilometres.

These initiatives can be incorporated into national and regional decarbonisation strategies for freight transport. The paper has outlined how such strategies can be formulated using a ten-stage procedure, devised initially for businesses but now adapted for use by national government agencies. It has also identified a series of macro-level indicators that would help governments to develop, implement, monitor and evaluate decarbonisation policies for freight transport. None of the Central and Southeast Asia countries currently collect data on this range of metrics. Nor, to our knowledge, does any other country, even those with a much longer tradition of freight data collection.

The paper also recommends adopting a life-cycle approach to collecting and analysing freight transport emission data, which supplements tailpipe emissions with emissions from upstream energy supply chains and embodied emissions in transport infrastructure. The case for such a life cycle assessment is particularly strong in Asian countries whose transport infrastructure is currently undergoing major enhancement. The spatial and modal configuration of that infrastructure and the standard to which it is constructed and maintained will have a lasting impact on the carbon intensity of freight movement in these countries.

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