Economic & Financial Analysis

Economics

Asia's race to net-zero carbon: 12.4 trillion dollars and counting

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Summary

China, Japan and South Korea have pledged to achieve net-zero carbon by the middle of the century. We estimate the capacity costs for just the transport sector alone at US$12.4tr. Total costs will be multiples of this. But act now and it could be achievable. Just.

Key takeaways

- Achieving net-zero carbon in just the transport sector alone in Japan, China and Korea will cost these economies around US$12.4tr in total in new electricity generating capacity.
- This is equivalent to more than 90% of China's 2020 GDP.
- But spreading this expenditure over the next 30 years (40 in the case of China) means that it is equivalent to only 1.8pp of Chinese GDP, 0.6pp of Japanese GDP and 0.6pp of Korean GDP.
- These are manageable sums, though transport only accounts for 20-30% of total energy consumption in these economies. The cost of transition for the whole economy is likely to be multiples of this.
- Even so, while the sums sound on the margins of credibility, we believe these targets are achievable, though foot-dragging now could put them out of reach.

Transport sector differences

Some sectors look easier to transform than others. Rail transport is already largely electrified. Though as a mature form of transport, it may struggle to find additional efficiency gains in the decades ahead.

Road transport is already on the right path in China with rising numbers of electric vehicles. It also benefits enormously from the inherent efficiency of electric vehicles compared to those which are conventionally fuelled.

The aviation industry's best bet may be sustainable aviation fuel (SAF), though we need to be careful how we account for the carbon sequestered in making SAF to ensure this really is carbon neutral.

Marine transport looks tricky. Ammonia looks on paper to be the best bet, but it requires a lot of energy to make and delivers little unless combined in complicated hybrid systems with hydrogen. This could be expensive.

Hydrogen hype?

The hype over hydrogen also seems overdone. As a primary energy supply, hydrogen offers few advantages to electricity and quite a few disadvantages. But it may have a role where grid supply is unavailable or as a storage unit for surplus green energy.

Some mitigation measures are inevitable

While we think it would be possible to run a transport sector on an absolute carbon-neutral basis, we concede that practical difficulties mean that carbon capture and storage will inevitably have to play a role in a target for net rather than absolute zero carbon. There is still a lot of progress to be made here.

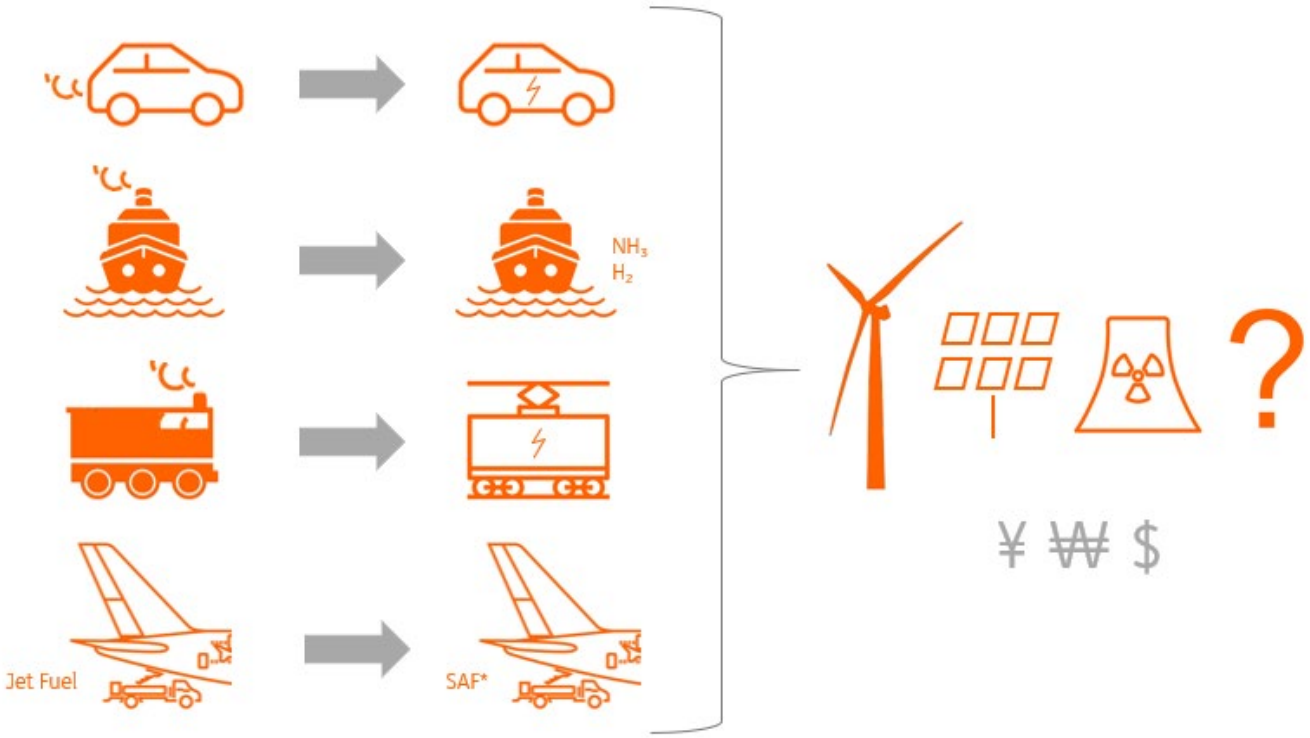
Introduction to "counting the cost"

How much are firms and governments going to have to spend transforming their electricity generating capacities to meet the demands of a future net-zero carbon transport sector? It's a question that will shed light on the cost and credibility of the overall economic transformation for the three Asian economies that have so far pledged to hit net-zero carbon emissions. In this introduction, we explain what we have done and how we reached our total cost estimate of more than US$12tr.

What are we trying to do and how?

Japan, China and South Korea account for almost two-thirds of all carbon dioxide emissions in Asia Pacific, and about a third of such global emissions. Net-zero carbon emissions require a total transformation of the energy-intensive sectors of their economies. In the following three short country notes, we start by looking at what the transformation of the transport sectors of these economies would cost in terms of electricity generating capacity requirements for these countries in line with their pledges to achieve net-zero carbon emissions.

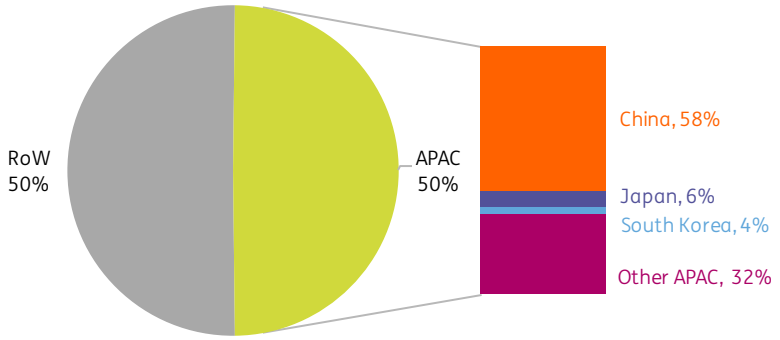
How much is it going to cost for Asia's economies to achieve net-zero carbon in transportation?



*Sustainable Aviation Fuel
Source: ING

By considering the electricity generating cost implications of transition for these three economies, we realise that we are just scraping the surface of what will inevitably be a much bigger and more complicated problem.

Asia's emissions of Carbon dioxide as a proportion of the global total



Source: Global Carbon Atlas

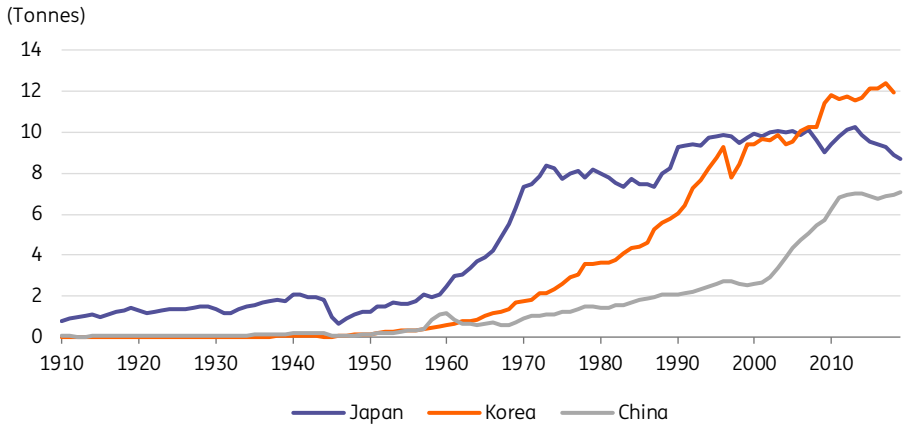
Our motivation for performing this analysis is that if the amounts for just this small part of the energy transition process are negligible, then potentially, the overall transition cost may be more manageable than many currently fear. If the costs are enormous, then it draws a question mark over the credibility of these national pledges.

What are we not trying to do?

At the outset, we want to note what we are not trying to do with these reports. We are not, for example, conducting a comparison of the levelized costs of alternative methods of zero carbon electricity generation. We also won't seek to argue how a country *should* meet its net-zero carbon pledge.

Beyond the capital costs of electricity generating capacity investment, our analysis does not consider the costs of other infrastructure spending. For example, the costs of installing E-vehicle charging points or adjustments to other sectors of the economy. We aren't trying to calculate how much carbon this saves or how much this reduces emissions. We have a hard end-point target to reach: net-zero carbon.

CO_2 per capita (tonnes)



Source: Our World in Data

Moreover, while we refer throughout to the net-zero carbon pledges, our calculations are all essentially absolute-zero. While net-zero is a credible target for the whole economy, for sub-sectors such as transport, there seems little justification for trying to calculate the costs of only a partial adjustment first.

We also consciously omit potential energy savings from refining crude energy sources (energy transformation). This is a substantial proportion of many countries' energy

balance sheets. For a full economy assessment, including these could well be appropriate.

Efficiency gains and measurement

Our analysis is also agnostic on technology. In earlier ING reports, our colleagues have looked at the role of technology in the global transition process. In this analysis, we also allow for efficiency gains (learning costs) during the transition. But unlike our other research, how the economy gets from A to B is not our main concern. What matters here is that we assume net-zero *is* achieved by the endpoint.

Our calculations for these three economies suggests that around US$12.4tr in total will need to be spent to provide the additional sustainable electricity generating capacity needed to make the transition for the transport sector for these three economies, with China bearing the brunt of this spending. If this sum seems unrealistically large, consider how much money is being spent on Covid measures around the world right now. We would argue that in terms of magnitudes, and considering the longer timeframe for these expenditures, they are plausible.

As far as the different sectors are concerned, marine seems to throw up the most problems and tends to be the costliest sector, though this is not to underplay the challenges elsewhere.

Most of these costs are likely to be met by the private sector and could be financed with green bonds, other existing sustainability linked instruments, or by green financial tools that have yet to be invented.

The figures we present are subject to a great many data inputs and assumptions. In the following methodology, we set out in some more detail the calculation process.

Methodology

The flow diagram that follows provides a stylistic description of the calculation approach used for passenger cars, though it is similar to other transportation modes. The starting point for all estimates is always the latest data on energy usage by transport sectors. In most cases, this is available from departments for energy or industry, and so is reliably hard data. We use 2019 data typically (2020 was anomalous…)

The next step is to forecast energy demand for that transport type by 2050 (2060 for China). We model the current pattern using simple econometric models, based on population growth, GDP or GDP per capita, proxies for transport cost (crude oil) and so on.

From this model estimate, we forecast an equivalent 2050 energy demand figure using forecasts of the input variables. Population forecasts are extremely reliable, so these parts of the forecast are solid. Long-run GDP forecasts too, are reasonably reliable (and, to an extent, are population-driven). Some other inputs are more subjective, though these tend to have low explanatory power.

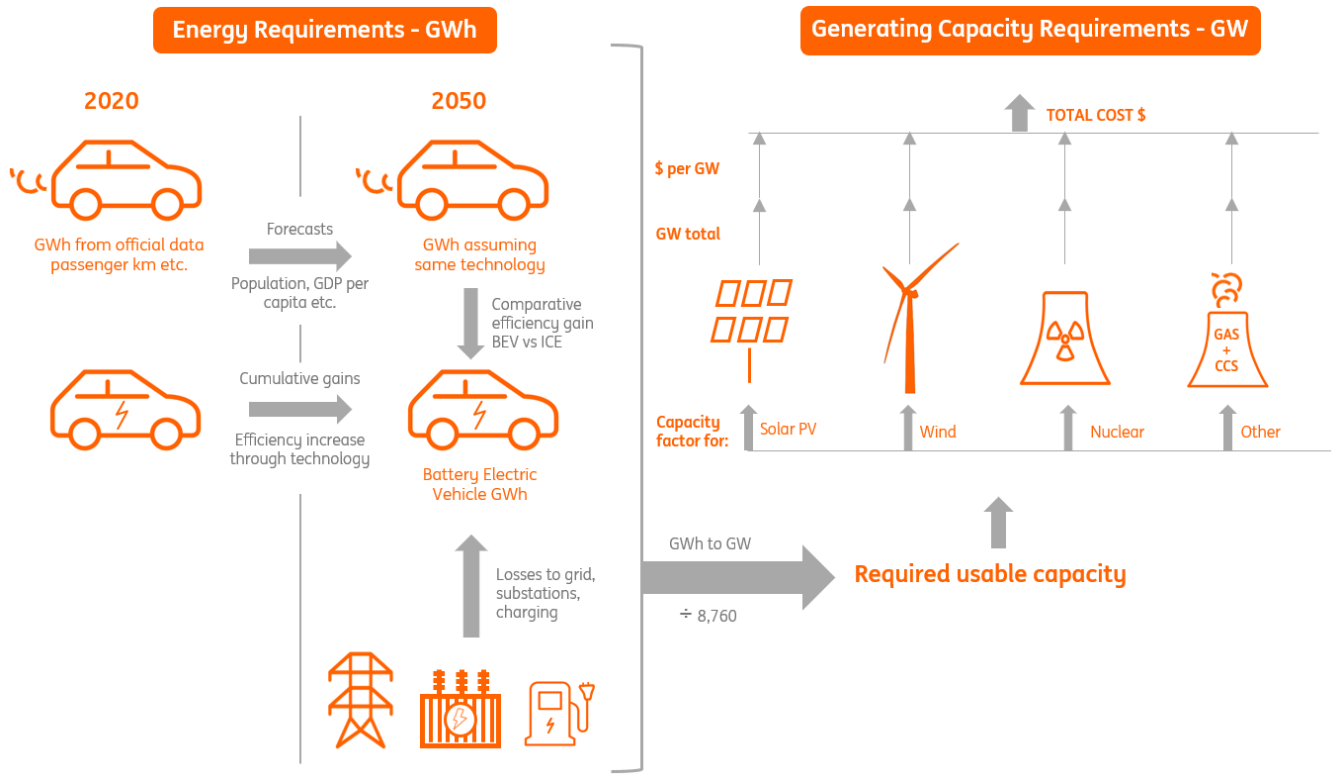
Adjust for new technology and technological progress

From these forecasts, we can calculate an energy requirement based on today's vehicle technology. We then adjust this for the transport technology we think will dominate by 2050. This is a subjective assessment. In some cases, such as passenger vehicles, there is a clear economic choice (battery electric vehicles – BEVs). In others, marine and air transport, for example, the choice is less clear.

There are already reliable comparisons of the efficiency of various vehicle types including conventional gasoline/diesel, battery electric vehicles, hydrogen fuel cells, and so on. We've taken estimates from the US Department of Energy amongst others to adjust future energy requirements from the constant technology calculations.

We adjust this future energy requirement for assumed technological improvements using a constant cumulative increment. This is the simplest possible approach, and at 1% cumulative efficiency gains per annum, we've set the gains at a level which is low relative to recent progress, so although we acknowledge the technology issue, we remain very conservative.

Stylistic methodology for calculating the cost of transformation to net-zero carbon for passenger cars



Source: ING

Convert energy required (GWh) into capacity (GW) – generating mix critical

At this point, we have our technology-adjusted energy requirement for the vehicle type in question, and we need to convert that into an electricity generating capacity and cost.

The first stage is to take a GWh energy figure and turn it into a simple GW capacity figure.

To figure out how much this generating capacity will cost, we need to know what proportion will be solar photovoltaic (solar PV), what proportion onshore and offshore wind and so on. We use official projections where possible.

In cases where the guidance lacks credibility, we have made allowances for what look to be policy goals made in a time of rapid change. These will inevitably be modified and we have tried to pick a position we feel is more consistent with longer-run goals.

The generating capacity mix also has to be adjusted because much of the renewable generating capacity is sporadic and requires other generating approaches to bridge periods where they aren't generating. To do this, we use the capacity factors published by the International Energy Association (IEA) to scale up the capacity required.

From usable capacity required to the capacity cost

Turning these capacity figures into a cost, we've used capacity costs published by the IEA (sometimes referred to as overnight costs). This is an extremely simple and arguably unrealistic concept. But it makes sense given that we are trying to describe a 20-30-year

process where we have no idea of the path of travel and only a solid idea of the start and endpoints. This approach provides a simple way of encapsulating the scale of the sums of money involved without having to consider financing costs, the speed of implementation, or net present values etc. The approach may be somewhat unrealistic, but the figure it produces is at least intuitive.

Helpfully, the IEA provides estimates of capacity cost for different countries and different generating technologies in 2020 and 2050. We have used these to calculate an average cost over the period, which assumes the constant investment profile we alluded to earlier.

There are some yawning uncertainties

Of course, not all transport types are as easy as road passenger transport to estimate. In these cases, we've moved further from "fact" and established "convention" and more in the direction of assumption and in some cases, pure guesswork. Wherever we have done this, we've tried to indicate where our assumptions come from, and you can decide for yourselves if these approaches invalidate our estimates or simply add uncertainty about their accuracy. Like it or not, there is sometimes no alternative to a reasoned guess in fields like this.

We have also presented the estimated cost as a single figure. We think it would be unhelpful to deliver a range of scenario figures so large that it answered no questions at all. But we are certainly not trying to claim that our estimates are not subject to considerable uncertainties and scope for error. They are.

Macroeconomic implications

We don't want to make too big a deal of the macroeconomic implications of all this. There are so many unknowns that doing so seems unrealistic. But it is important to recognise what our calculated spending figures mean. The temptation is to think of this total as a "cost" of transition - a "drag" on business activity and a "loss" of competitiveness. And if we were considering a single firm or a single industry transforming relative to the bulk which were not, then this might indeed be a reasonable interpretation.

But this isn't what we are describing here. These processes we are calculating are being undertaken by three of the largest economies globally, not just in Asia. And against a backdrop where other global economies are doing the same.

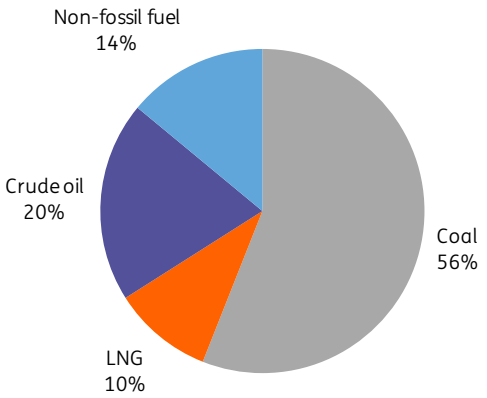
All this spending is actually business and government investment. It contributes to GDP. One firm's cost will be another firm's revenue. Aggregate activity could well rise rather than fall as a result.

We think the best analogy for this is the comparison with a period more than twenty years ago when economies around the world were undertaking preparations for Y2K. There was vast spending on IT upgrades and measures to prevent a hypothetical information apocalypse. Whether or not any of this expenditure was ever necessary is irrelevant. What is important is that the process led to extremely strong business investment growth, which in turn, drove GDP higher, leading to rising productivity growth. There would have been other factors involved, but in using up surplus global savings, 10Y US Treasury yields rose by more than 200bp in the two years leading up to the new millennium. For stagnating economies such as Japan, a prolonged period of rapid investment growth may provide a catalyst for economic growth that has been absent for decades.

China

China is the world's biggest emitter of carbon dioxide. Its increasingly upper-middle income economy is becoming a mass market for technology manufacturing. China has the biggest fleet of electric vehicles in the world but is still heavily reliant on fossil fuels. The environment, however, is becoming an ever more important political priority

China primary energy source, 2020



Source: CREO

China is regularly labelled as one of the most polluting economies on the planet. But the environment has become an increasingly important political priority in China and in December 2020, the central economic workforce decided to set a target for achieving net-zero carbon emissions by 2060, and peak carbon emissions before 2030[1].

The government has since released a few papers on how to achieve these two targets. One is the 14th Five Year Plan, which provided detailed targets on greening the economy for 2021-2025, including reducing CO_2 emission by 18% by 2025. Another is the New Era of China Energy Development published in December 2020, which set the policy direction in section 4. In February 2021, the National Development Reform Commission (NDRC) issued further guidance[2] to speed up the transition to a green economy.

In addition to internal government policy papers, the Chinese government has also teamed up with international bodies to study the roadmap for reaching net-zero carbon emission targets by 2060. The studies include China 2050: A fully developed rich zero-carbon economy by the Energy Transitions Commission and China Renewable Energy Outlook 2019 (aka. CREO) by the Energy Research Institute of Academy of Macroeconomic Research / NDRC China National Renewable Energy Centre with technical support from various European energy agencies, including the Danish Energy Agency and Germany's Energy Agency.

We apply the CREO's estimate of electricity generation from renewable energy sources of around 65% to reach net-zero carbon emission. Then, as we have done for Korea and Japan, we combine this data with the IEA's data[3] for capacity factors and capital costs per KWh for different modes of energy generation to arrive at a weighted cost for incremental electricity capacity requirements to attain net-zero carbon emission.

[1] http://www.nea.gov.cn/2021-04/30/c_139917008.htm

[2] NDRC (2021) No. 4

[3] IEA World Energy Outlook Annex B Table B 2b

China's electricity generating mix 2060

	Nuclear	Gas CC	Solar PV	Offshore wind	Onshore Wind	Hydro	Hydrogen
China Prospective weighting	0.05	0.293	0.316	0.1575	0.1585	0.01	0.015
Capacity factor	0.8	0.5	0.18	0.35	0.26	0.45	0.5

Source: CREO. ING

Like our other country calculations, we assume for China that both the generating processes, as well as end-use transport will become more efficient over time. Consequently, our average cost per GWh of electrical work, energy and per GW of capacity will be lower by 2060. As noted in the introductory section to these country reports, we make the simplest assumption possible about the installation process, and our capacity costs are consequently a simple average of the 2020 costs and the 2060 costs for China.

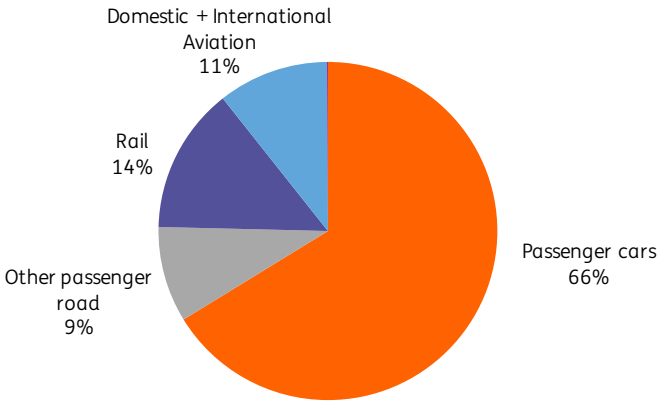
Here is how it breaks down for China:

Land transport – Passenger cars

Total energy demand from transportation was 14% of total energy demand in China in 2018, which was around 25,725,560 GWh. Among all types of passenger transport, passenger cars consumed the lion's share, with 66% of total transport energy consumption. That is to say, passenger cars accounted for around 9% of overall energy demand in China in 2018.

Passenger transport is dominated by cars

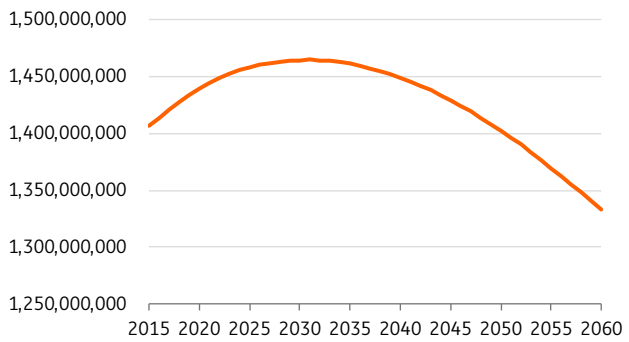
China passenger transport (bn)



Source: Energy Transitions Commission, China 2050, page 37-39

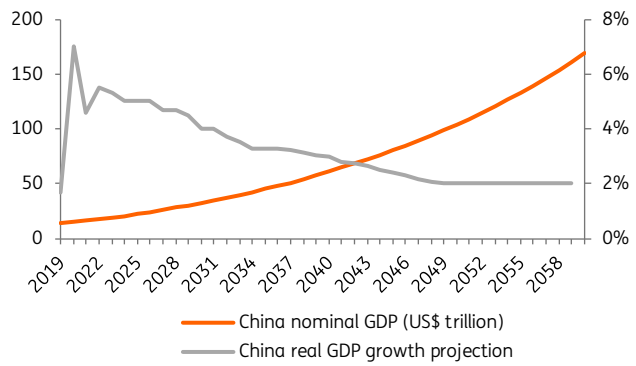
The CREO estimates that there will be 450m passenger cars in 2050, up from 220 million in 2018. This increase will be driven by 1) urbanisation and 2) wealth increases, which will offset the negative influences of a declining and ageing population. We further assume that the number of passenger cars won't change from 2050 to 2060 as ageing will speed up while the process of urbanisation should have been largely completed.

China population projection by United Nations



Source: UN

China nominal GDP vs China real GDP growth projection



Source: CEIC

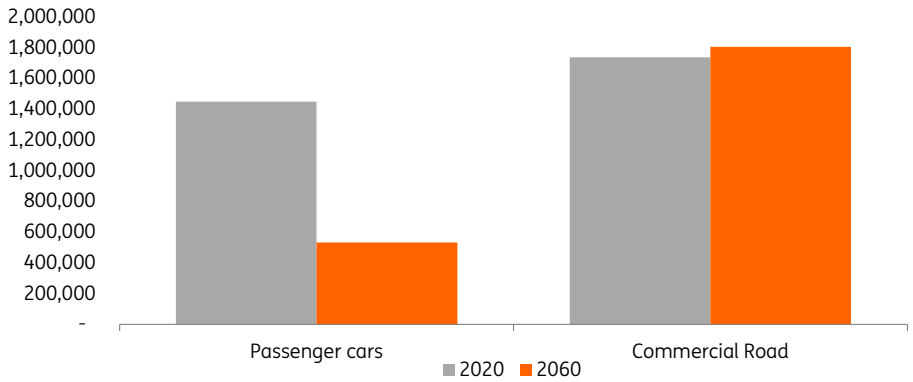
Just as for Japan, partly for simplicity, but also because it seems unambiguously the most energy efficient approach, we have assumed that all passenger vehicles by 2060 are battery plug-in electric vehicles (BEVs) compared to the current fleet, which has only about 5 million "new energy vehicles" out of the total fleet of 220 million[4]. This will deliver an immediate benefit in terms of energy efficiency gains compared to internal combustion powered vehicles. Total energy demand from passenger vehicles by 2050 could be as low as 79,500 GWh.

Backing out the electricity generating capacity required to deliver this energy requirement, and accounting for China's projected generating mix, this will require only around 61GW of additional generating capacity at a total cost of US$516bn, or less than 0.09% of GDP on an annual basis if spread out over the entire horizon (i.e. from 2020 to 2060). This is only one part of the whole transport sector though and as noted for Japan, this surprisingly low result stems from:

- The inherent efficiency improvements of BEVs compared to the current fleet
- Additional efficiency gains for BEVs by 2060
- Decline in costs especially for renewable energy as it becomes more widespread.

Let's now consider the other types of transportation.

Energy consumption (GWh) in China between 2020 and 2060 by mode of transportation



Source: ING

[4] https://www.marklines.com/en/news/248483

Commercial vehicles:

We perform a similar calculation for buses and trucks. Road freight will increase to 29 trillion tonne-km in 2060 from 7.1 trillion tonne-km, contributing to 58% of total freight volume[5].

BEV is a less obvious choice for long haul commercial vehicles even if it is the economic choice for buses, as China has increased the use of BEV for buses.

Hydrogen fuel cells could be an alternative energy source for long haul trucks but while these are highly efficient vehicles compared to internal combustion engines, there are efficiency leakages in transport and re-filling, and the hydrogen production process is extremely energy intensive. So even for long haul vehicles, where the benefits of regenerative braking are less useful, it is not a clear choice.

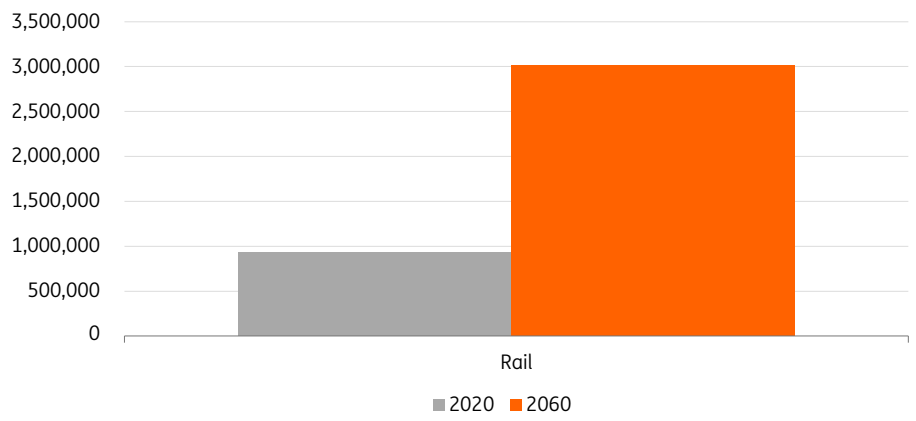
Our calculations show that adopting green technology by commercial vehicles will require an additional 206GW of capacity and US$1,750 bn of capital costs, equivalent to 0.29% of GDP per year from 2020 to 2060.

Rail system

In contrast to Japan, China's passenger rail demand is likely to increase to close to 4 trillion passenger-km in 2060[6] from 1.415 trillion in 2018 as there will likely be more trips per passenger in the future as wealth levels increase. Rail freight looks likely to grow strongly, too. CREO calculates this will grow by 260% to 7.4932 trillion tonne-km, up from 2.882 trillion in 2019 as more freight moves from air to rail.

We find that an additional 344GW of capacity will be needed to supply the rail system at a cost of US$2921bn, equivalent to 0.49% of GDP in 2020 terms each year over 40 years.

Rail energy consumption (GWh) in China



Source: ING

Aviation

In 2018, aviation in China had just over 1 trillion passenger-km and 27bn tonne-km of freight, using around 63bn litres of jet fuel. Most of the recent growth in aviation in China comes from passenger travel, which is expected to grow 5.4% p.a. for 20 years from 2018[7].

We expect that air cargo growth will be around 5.35% annually as the economy develops. There will be an increase in demand for perishable produce, e.g. food and

[5] The Energy Transition Commission, China 2050 Page 40.

[6] CREO page 136

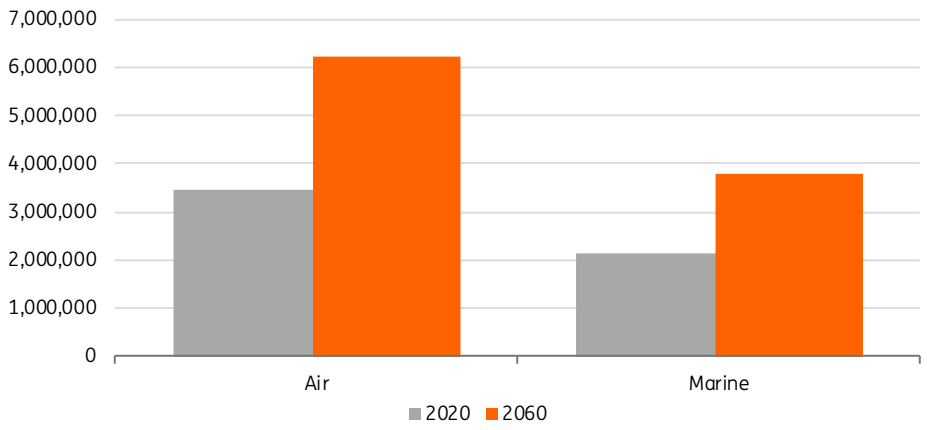
[7] https://www.airlines.iata.org/news/china%E2%80%99s-domestic-aviation-industry-showing-upward-trend

plants. Slower growth in air cargo could continue with better rail networks within China and with increased rail links to Europe[8].

China expects that most jet fuel will be fossil fuel by 2050. And at this stage, hardly any China policy documents mention the use of sustainable aviation fuel (SAF) in the future for China. There is a plan to initiate the development of a roadmap for SAF in The Roundtable on Sustainable Biomaterials[9]. But electrical power demand to produce SAF is high[10].

If, however, we assume that China also aims for 100% SAF by 2050/2060 (otherwise, this has to be offset with huge mitigation efforts - carbon capture is not practical for aircraft) then we calculate that China will use 6,226,763 GWh by 2060 for aviation, which implies a cost of US$2021bn, equivalent to 0.34% of GDP in 2020 terms for each year from 2020 to 2060.

Aviation and marine energy consumption (GWh) in China



Source: ING

Marine

Like Japan, marine transport is almost entirely freight. We can ignore the passenger sector as a result.

As we noted in the Japan note:

> *"There are widely differing outlooks on the future for shipping fuel. With some advocating a short-term shift to LNG as a bridging fuel. But with increasing concern about "methane slip", one of the world's biggest shipping companies, Maersk, has come out strongly against that. LNG is also a fossil fuel and even ignoring methane slip, which is hard to do, countries like Japan would need to mitigate against the CO_2 emissions, and shipping companies needing to buy new ships might find them unprofitable within their economic lifetime.*
>
> *The alternative fuel source is ammonia."*

China's own specification on green sea freight helps lower this high cost a little. Demand for sea freight is estimated to be around 120% of today's levels by 2060. But the increase in demand for energy from additional shipping will be offset by reduced energy

[8] https://www.railfreight.com/beltandroad/2021/03/05/nippon-express-launches-new-europe-china-train-amidst-booming-demand/?gdpr=deny

[9] https://biofuels-news.com/news/rsb-launches-new-research-into-chinese-sustainable-aviation-fuel-market/

[10] https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

use following China's own standardised technical specifications for green designs for ships[11], and, China's green policy to speed up replacing and transforming old ships with greener ships[12]. These two policies are estimated to offset 60% of sea freight energy use between now and 2060.

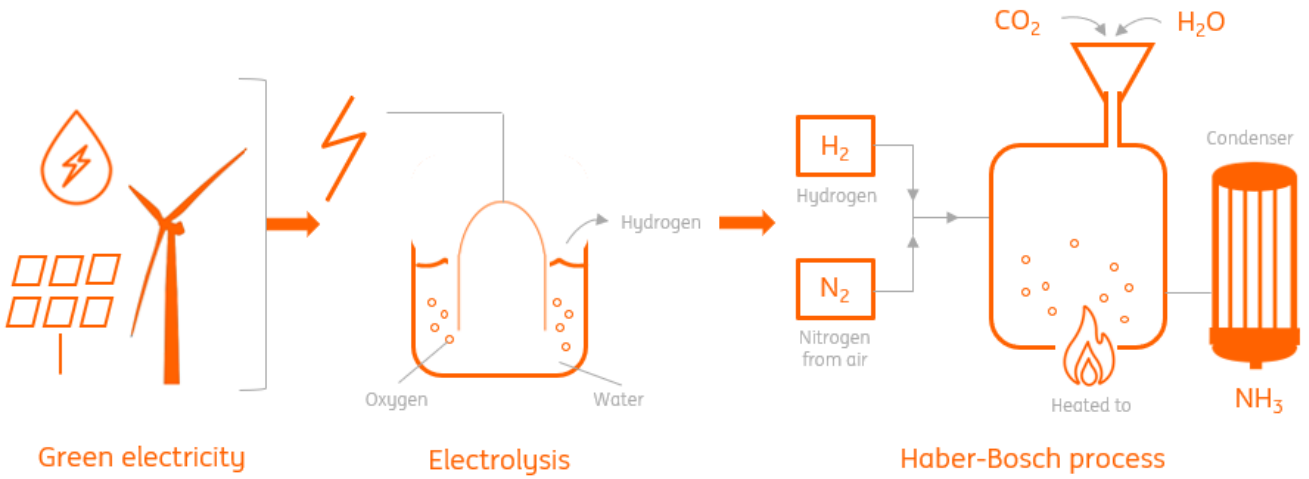
It is questionable whether the estimated growth of sea freight of 120% between 2021 and 2060 is too small. But we have also considered that high investment costs will be passed on to users and they now have some alternatives, for example China-Europe rail[13].

The additional electricity generating capacity costs to create green ammonia for shipping would require an additional 433GW of capacity with a capital cost of US$3,679bn, equivalent to 0.61% of 2020 GDP each year until 2060. It is extremely costly to shift completely from diesel and LNG to green ammonia.

One alternative would be to import the ammonium or hydrogen from overseas. For example, blue ammonia from the Middle East with appropriate local carbon capture and storage measures or green hydrogen from countries with abundant wind, solar PV, hydro-electric or geothermal power sources.

However, this basically just externalises the costs of capacity installation, and creates an ongoing cost to the economy in terms of the net drain on GDP from imported green energy.

Green Ammonia Production



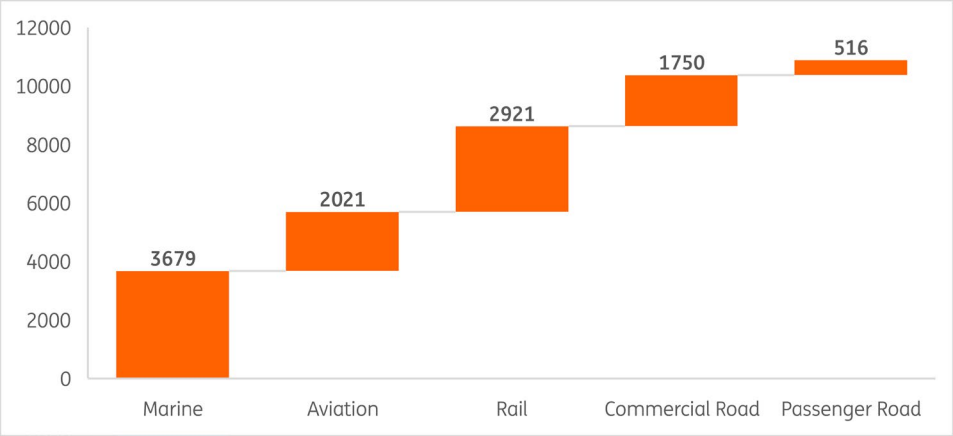
Source: World Economic Forum, ING

Conclusion

When we add up all the costs to achieve net-zero carbon emissions for the transport sector in China, it amounts to about US$11 trillion (US$10.9tr), which is 1.8% of China GDP in 2020 terms per year for 40 years. The marine sector needs the most investment to be entirely zero carbon by substituting diesel and LNG with green ammonia, followed by rail then aviation. This study shows that the cost of achieving zero carbon emissions for the transport industry is extremely high. And this only considers investment costs for electricity generation for the transportation industry. These costs will likely be shared by the government and the private sector.

[11] http://www.cansi.org.cn/ifor/shownews.php?lang=cn&id=16122
[12] http://www.cansi.org.cn/ifor/shownews.php?lang=cn&id=15730
[13] https://www.dsv.com/en/insights/expert-opinions/rail-freight-between-europe-and-china

Additional capital costs required to achieve zero carbon emission by 2060 for China (US$bn)



Source: ING

In contrast to our figures, the People's Bank of China governor estimated CNY141 trillion in investment would be required for CO_2 reduction (equivalent to US$23.5 trillion at a USD/CNY exchange rate of 6.0). However, that was a figure for the full economy. Our calculation is for just part of the transition process. Whatever the sum, the amounts are considerable, and some will be funded by the market in the form of green bonds, green loans and other sustainable finance instruments.

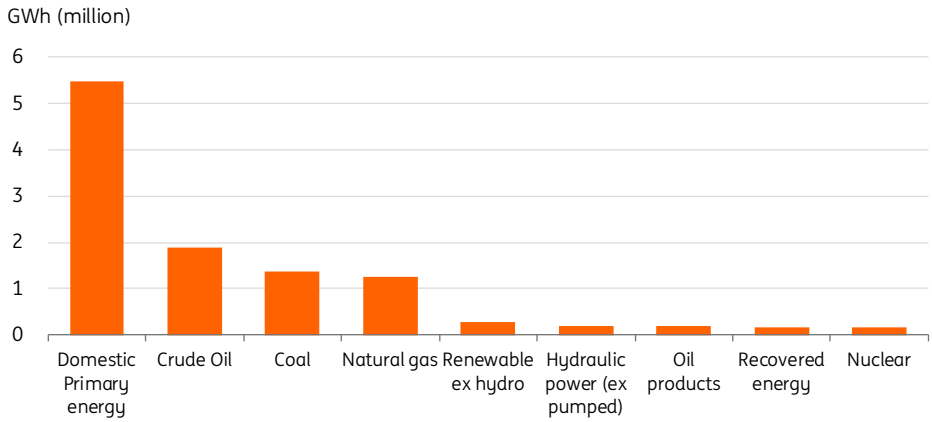
As of the end of 2020, China's green loans outstanding stood at around US$1.8tn with green bonds outstanding at US$125bn, ranking as the largest and second largest markets in the world for these instruments, respectively[14].

[14] http://www.ce.cn/xwzx/gnsz/gdxw/202104/16/t20210416_36478533.shtml

Japan

Japan aims to be net-zero carbon by 2050. Although it's at the forefront of many technologies, it's made little progress in terms of decarbonising its economy and fossil fuels make up more than two-thirds of its primary energy supply. We estimate the electricity generating transformation costs for Japan's transport sector are around US$1tr.

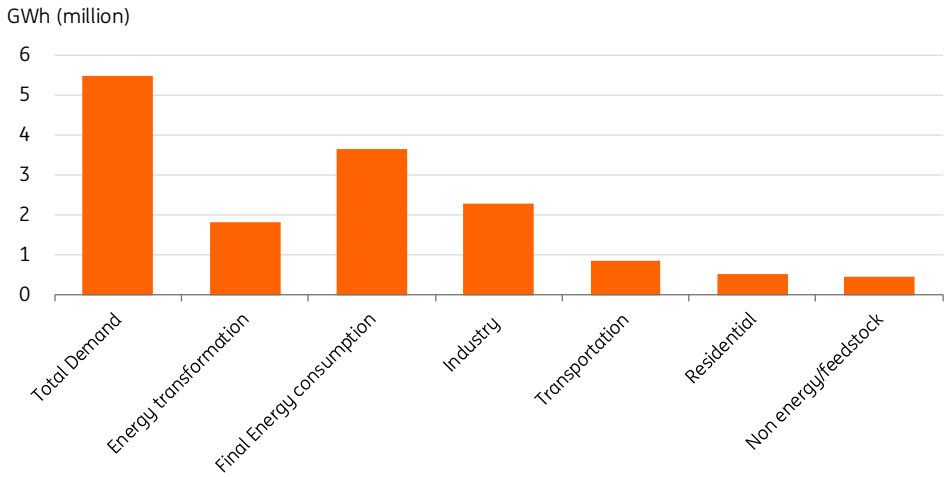
Japan's energy sources



Source: Japan Bureau of Statistics - statistical yearbook 2021

Japan is a heavy emitter of greenhouse gases even by developed market standards, but that also means there is a lot of low hanging fruit in the transport sector and in the electricity generating sector that will enable it to make some quick wins if it is determined to do so. That said, transport only accounts for a small proportion (23%) of Japan's final energy demand.

Demand for energy by sector: Japan



Source: Japan Bureau of Statistics - statistical yearbook 2021

The Japanese government issued its "Green growth Strategy Through achieving Carbon Neutrality in 2050" shortly after PM Suga declared this objective in October 2020.

In the MITI paper that followed, the government set out a goal to generate 50-60% of all electricity demand with renewables by 2050, with 10% coming from hydrogen and ammonia power generation, and 30-40 from nuclear and thermal power plants with carbon capture and storage to cover the rest.

What we have done is to take these rough targets as guides for Japan's electricity generating capacity[15]. We have used IEA figures for capacity factors[16] for different types of generation (how much a type of generation can be relied on compared to its theoretical maximum capacity) as well as capital costs per KWh[17] and calculated the weighted costs for incremental electricity capacity requirements stemming from the transition to net-zero carbon.

Japan's electricity generating mix - 2050

	Nuclear	Gas CC	Solar PV	Offshore wind	Onshore Wind	Hydro	Hydrogen
Japan Prospective weighting	0.15	0.15	0.25	0.125	0.125	0.1	0.1
Capacity factor	0.8	0.5	0.18	0.38	0.26	0.45	0.5

Source: IEA, ING

For each part of the transport transition, we calculate the demand for transport by 2050 and then derive the electricity demand that the most practical zero-carbon alternative would require. We take account of losses in electricity transmission and work backwards from this calculated energy requirement. We back out the capacity change needed to provide that additional power and the cost of installing that capacity.

We note that both the generating processes and end-use transport are becoming more efficient over time. And so, our average cost per GWh of electrical work, energy and per GW of capacity will be lower by 2050.

As noted in the introductory section, we make the simplest assumption possible about the installation process, and our capacity costs are consequently a simple average of the 2020 costs and the expected 2050 costs.

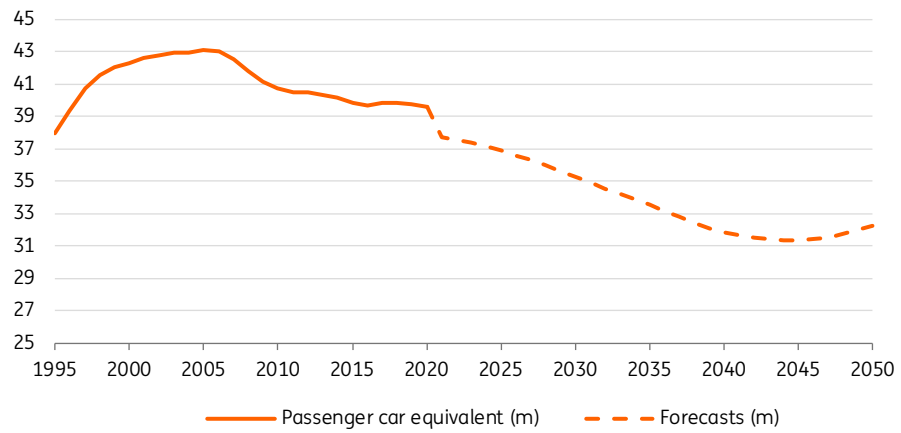
Land transport – Passenger cars

Total transport energy demand for Japan in 2019 was about 15.5% of the total primary energy demand, accounting for approximately 850,000 GWh. Of this, about 59% was passenger traffic, and 59% of that was passenger cars.

With 98% of the Japanese vehicle fleet conventional or hybrid, a net zero-carbon passenger vehicle world will require replacing almost the entire fleet.

With its shrinking and ageing population, together with its slow GDP growth, our modelling of the passenger vehicle segment for Japanese road transport shows the continuation of the trend decline evident since around 2005 continuing until about 2045 before it starts to level off.

Japan passenger vehicle forecast



Source: CEIC and ING

[15] IEA Japan 2021 Energy Policy Review
[16] IEA World Energy Outlook Annex B Table B 2b
[17] IEA Projected costs of Generating Electricity 2020

For simplicity, we have assumed that all passenger vehicles by 2050 are battery plug-in electric vehicles. Japan has made a big play for the hydrogen fuel cell as a potential future source of clean energy for vehicles. But compared to battery EV's, these are less efficient and do not benefit to the same degree from regenerative braking in an urban traffic environment, which seems most appropriate to Japan's case.

Even today, plug-in electric vehicles are considerably more efficient than conventional internal combustion engines[18] [19]. By 2050, assuming a continuation of trend efficiency gains, they will be more efficient still. And if autonomous driving is also more widespread, which we think likely, reducing costly braking and acceleration, efficiency gains will be further improved[20]. With the decline in total vehicles on the road by 2050 and allowing for transmission losses at charging, distribution to the grid and substations, total energy demand from passenger vehicles in 2050 could be as low as 70-75,000GWh.

Backing out the electricity generating capacity required to deliver that, and accounting for Japan's projected generating mix, this requires only around 20GW of additional generating capacity at a total cost of US$54bn, or less than 0.1pp of GDP on an annual basis if spread out over the entire horizon. This low result is a result of:

i. The decline in vehicles on the road and passenger km by 2050

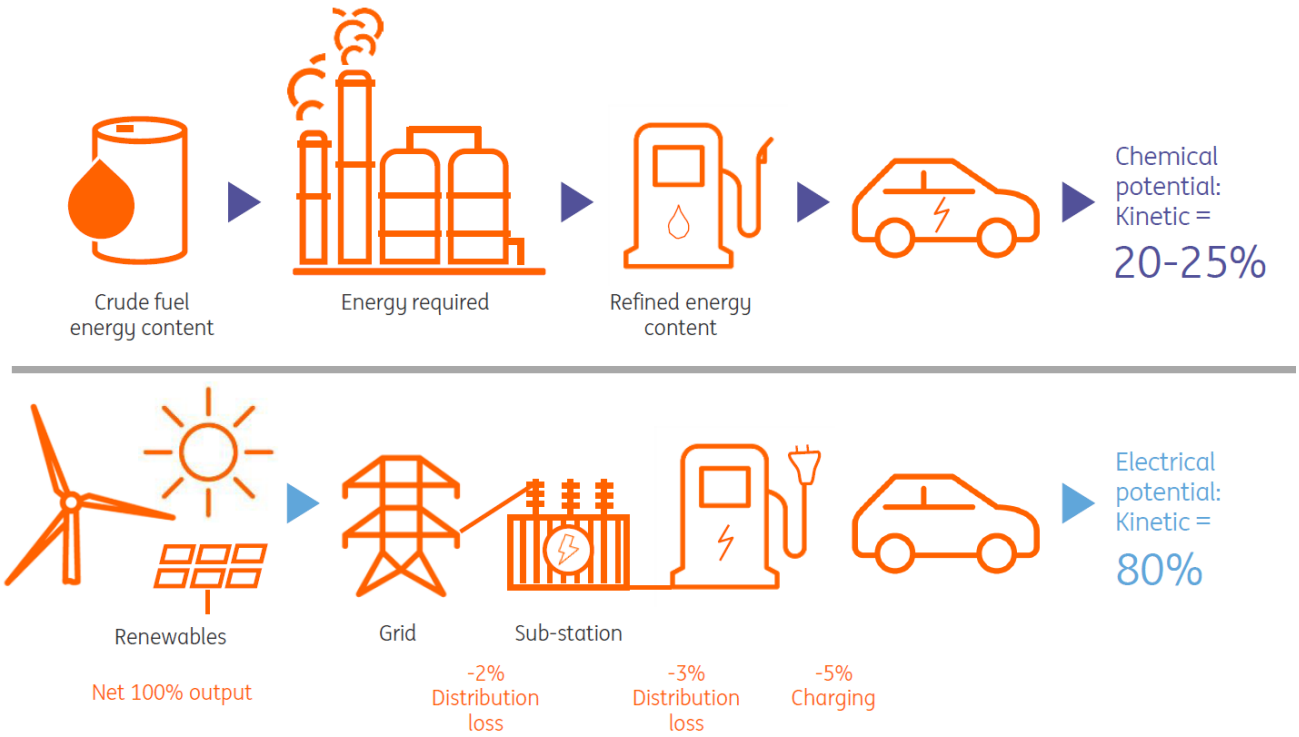
ii. The inherent efficiency improvements of BEVs compared to the current fleet

iii. Additional energy gains for BEVs in 2050 from now

iv. Decline in costs, especially for renewable energy as it becomes more widespread.

This is only one part of the transport sector, however. Let's now consider the other parts.

The efficiency of battery electric vehicles (BEVs) versus internal combustion engines (ICEs)



Source: US Department of Energy, ING

[18] https://www.fueleconomy.gov/feg/atv.shtml

[19] https://www.fueleconomy.gov/feg/atv-ev.shtml

[20] Energy Efficiency trade-offs in small to large electric vehicles. Environmental Sciences Europe, 18 March 2020.

Commercial vehicles:

We perform much the same calculation for buses and road haulage using trucks. Where BEVs were unambiguously the technology of choice for the urban passenger segment, this is less clear for commercial vehicles. For short-haul commercial transport, including buses, the efficiency gains and restorative braking technology mean that battery electric vehicles will likely be the clear economic choice. But for longer range traffic, it is not so obvious.

For fuel cell-driven vehicles, the issue of hydrogen generation requires some consideration to allow for net-zero carbon production. The electrolysis step is not 100% efficient, and then there are further leakages and efficiency losses at each stage of compression, liquefaction, transportation and filling. Even if, ultimately, hydrogen fuel cell vehicles are very efficient at turning that chemical potential energy into kinetic energy to shift the vehicle forward[21], the process for getting there is extremely complicated, and the overall efficiency gains smaller than for battery electric vehicles. That said, Japan's government has placed some considerable weight on hydrogen as part of its sustainability plans[22] and we believe it will be part of the land transport solution, though it will play a much bigger role, in marine transport (as ammonia).

Splitting the commercial vehicle sector into long haul, which could make good use of hydrogen fuel cell technology, and short-haul, which is more likely to benefit from battery power, we can make similar calculations to those done for the passenger vehicle segment. Doing this, we calculate this will require an additional 20GW of capacity and a further US$60bn of capital costs.

Japan's rail system

Rail is extensively used in Japan compared to many developed countries, and it accounts for 29% of current passenger transport energy consumption. Only about 5% of this rail transport is freight traffic.

Passenger transport was edging up prior to the pandemic when it collapsed (we show it only pre-pandemic for clarity). But for Freight, ton kms have been edging down for some time. With 85% of Japan's rail network already electrified, the only real gains to be made here are from full electrification of the remaining 15% of the network.

Annual passenger and freight ton km travelled

Source: CEIC

Even with the possibility that a falling and ageing population results in reduced rail usage over time, we are reluctant to convert this into a reduced rail energy usage. Timetabling constraints make it more likely that trains simply run a little less full as the

[21] https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work

[22] Basic Hydrogen Strategy December 26, 2017. Ministerial Council on Renewable Energy, Hydrogen and related issues https://www.meti.go.jp/english/press/2017/pdf/1226_003b.pdf

population drops. Likewise, for a transport mode that is so mature, we struggle to see substantial efficiency gains over the coming decades.

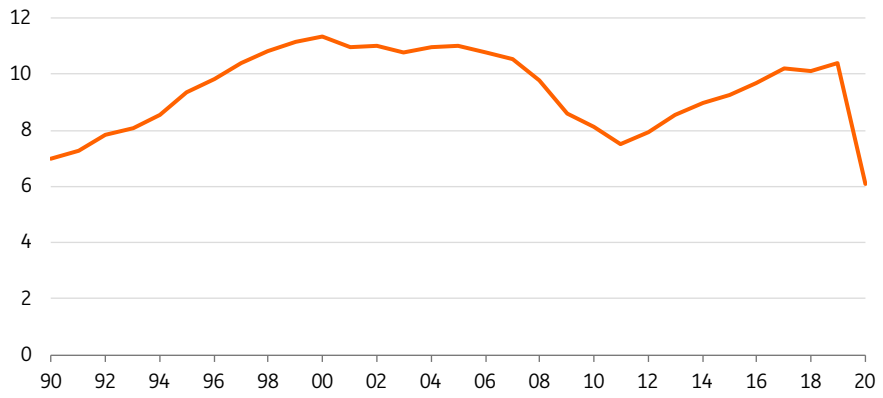
Consequently, we see rail as a simple calculation where we replace the existing energy generating capacity with net zero carbon capacity for a fully electrified rail network. We calculate that the total transformation will require an additional 60GW of capacity for a total cost of US$150bn.

Aviation:

It is easy to find articles about battery-powered planes or planes using hydrogen[23][24]. It's a lot harder to imagine the entire global fleet of commercial aircraft adjusting to a new power source, or for that matter, safely travelling on such an aircraft. For shorter flights, we consider France's recent move to ban internal flights where there is an alternative train journey of less than 2.5 hours as a more practical policy direction for countries in Asia like Japan, but ultimately, this is their choice.

For those remaining flights, the more credible alternative to hydrogen or battery power, we believe, is that current aviation fuel is replaced with sustainable aviation fuel (SAF) and used in existing aircraft. This could be done without the requirement to redesign and build an entirely new generation of aircraft. Bearing in mind that the Boeing 747, has only just been retired, after it was first used in 1970 by Pan Am, it is clear that there is a lot of life in the existing generation of commercial aircraft. If not, this could be one transport segment that requires mitigation efforts elsewhere. Though we are somewhat dubious about the credibility and scale of such measures as are currently available. And these will need to be adequately "policed" to prevent greenwashing.

Jet fuel used (kl million)



Source: CEIC

Sustainable aviation fuel, which can start off as food waste or industrial landfill, can arguably be net carbon negative in the sense that it replaces a methane source with a product that would generate a less harmful greenhouse gas, carbon dioxide. And there is apparently, no shortage of available feedstock. Though planes running on SAF still emit carbon dioxide. And we have to be very careful about how we undertake the carbon balance sheet accounting for processes like this. Are they genuinely reducing greenhouse gases from the atmosphere, or not? That needs to be made more clear.

Moreover, creating sustainable energy fuel is not an energy neutral proposition, and would require some significant energy inputs. One variant of this is described by the US Department of Energy, which requires 90MW of electricity generating capacity for each 10 million gallons of aviation fuel manufactured.

[23] https://www.bbc.com/future/article/20210401-the-worlds-first-commercial-hydrogen-plane

[24] https://www.flightglobal.com/airframers/swiss-company-h55-to-provide-batteries-for-harbour-airs-electric-beaver/143359.article

To manufacture a sustainable alternative to the 10.4 billion litres of aviation fuel Japan used in 2019 would require an additional 62GW of capacity at US$168bn, assuming that demand eventually crept back to 2019 levels and allowing for some further efficiency gains.

Marine

The Marine transport segment is perhaps the trickiest transport sector for these calculations. Japan's Marine transport sector is overwhelmingly freight, so we can ignore the passenger sector for the purposes of our calculations.

There are widely differing outlooks on the future for shipping fuel. Some advocate a short-term shift to LNG as a bridging fuel. But with increasing concern about "methane slip", one of the world's biggest shipping companies, Maersk, has come out strongly against LNG. Even ignoring methane slip, which is hard to do, countries like Japan would need to mitigate against the CO_2 emissions produced, and shipping companies needing to buy new ships might find them unprofitable within their economic lifetime if they had to offset rising carbon emission costs.

The most likely alternative fuel source we know about today is ammonia. This has both advantages and disadvantages.

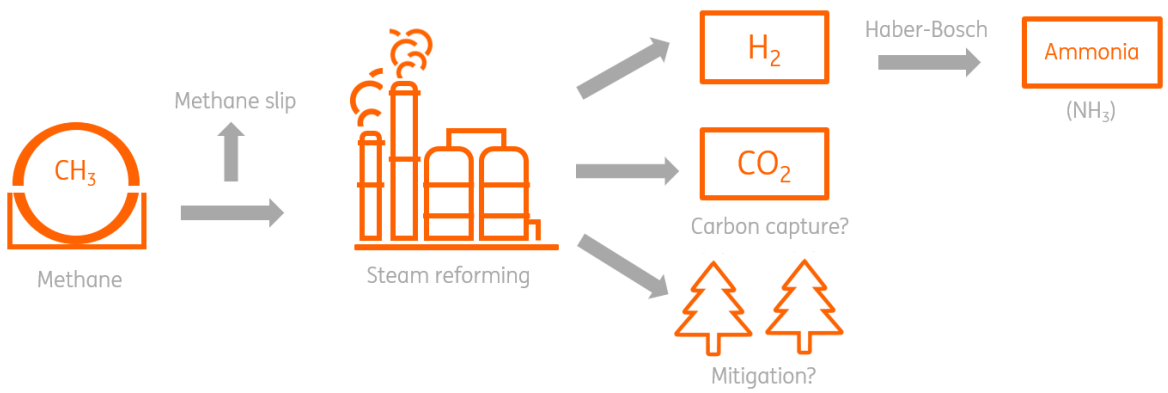
Advantages:

- When burned, it emits no CO_2
- It is fairly energy dense and so will not compromise marine cargo space.
- A tank of ammonia (NH3) contains more hydrogen than a tank of hydrogen (H2)
- Existing ships can be retrofitted with ammonia burning engines (though this would not be cheap)

Disadvantages

- Ammonia needs to be produced, which is an energy-intensive process deriving from reducing methane (blue ammonia), producing CO_2, which needs capturing and storing (untested and potentially uncommercial), or through green ammonia production, which requires a lot of renewable energy.
- Conventional engines for burning ammonia are not very efficient. Ammonia does not burn well on its own and is much more efficient when combined with hydrogen gas which also helps to reduce harmful NO and NO_2 emissions. In short, given the inefficiencies of such engines, the overall process requires a lot of energy input, for much less energy output.
- We won't consider the additional bunker costs here, but as ammonia is less fuel dense than traditional fuel, these would also be considerable.

Blue Ammonia production



Source: ING

Calculating the additional electricity generating capacity costs required to create green ammonia even if used in more efficient hybrid H_2 enhanced engines would require an additional 216GW of capacity at the cost of about US$588bn.

It might be possible to do this more cheaply with blue ammonia. But that would require carbon capture and storage (CCS) or mitigation actions, the costs of both of which are unclear. While we consciously gloss over CCS in this note, we aren't dismissing it entirely. Most of the net-zero plans we have seen for Asia, including those for Japan, include a role for CCS, usually alongside LNG gas turbine electricity generation. And it does look as if CCS will become a much more important feature of net-zero carbon transformations in the coming years.

Conclusion

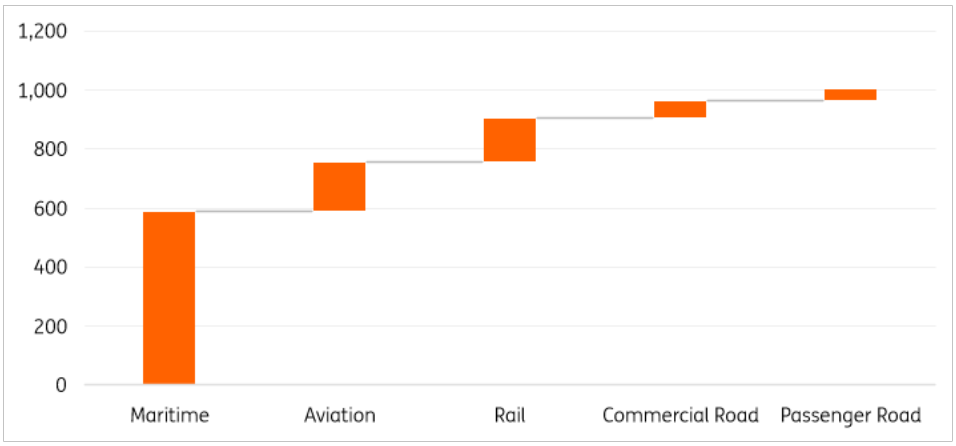
When you add all this together, the total costs for Japan in transitioning to a net-zero carbon transport system, would cost about $1tr purely in terms of the electricity generating capacity required.

In very rough terms, that is about 20% of current Japanese GDP, though this falls to around 0.6% of GDP per annum when spread between now and 2050. That's not much more in total than the Japanese government spent on Covid-19 mitigation efforts, just to throw in some more perspective.

But then this is only the transport sector, and only the electricity generating capacity cost we have considered. The whole economy transition will be far more expensive.

With government money earmarked for the transition of the entire economy less than 20% of the total for transport alone, it is clear that the private sector will be required to pay for most of this.

Additional capital cost required (US$bn)



Source: ING

That sounds alarming. But put this another way, for the transport sector alone, this transition will require additional private sector investment spending of about 0.6pp of current GDP per year. As far as GDP is concerned, one person's cost is another's income. So yes, this will be disruptive, but this is not simply a drag on growth and could reinvigorate what is currently a very lacklustre economy.

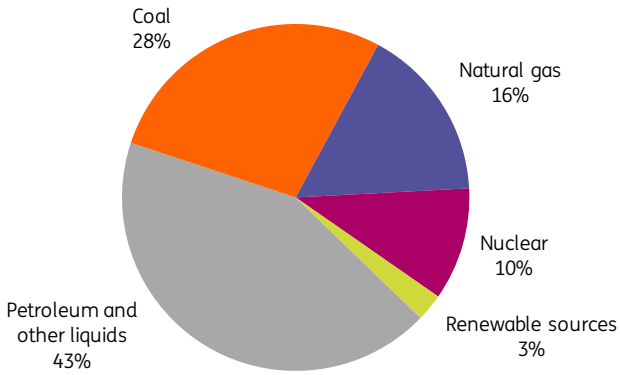
The Japanese government claim a total GDP gain from their green transition plan of US$1.8tr by 2050[25]. This is not a figure that we can completely dismiss. If we have any bias, it is that this might be too small.

[25] Overview of Japan's Green Growth Strategy through achieving Caron neutrality in 2050. Jan 2021

South Korea

Like Japan, Korea's primary energy demand is heavily reliant on fossil fuels, with petroleum and other liquids accounting for 43% of all energy consumption, and coal 28%. Nuclear fuel accounts for around 10%, and renewables only 3%. We estimate that transforming Korea's transport sector, like Japan would imply additional sustainable electricity generating costs of around US$400bn, or 0.6pp GDP per year

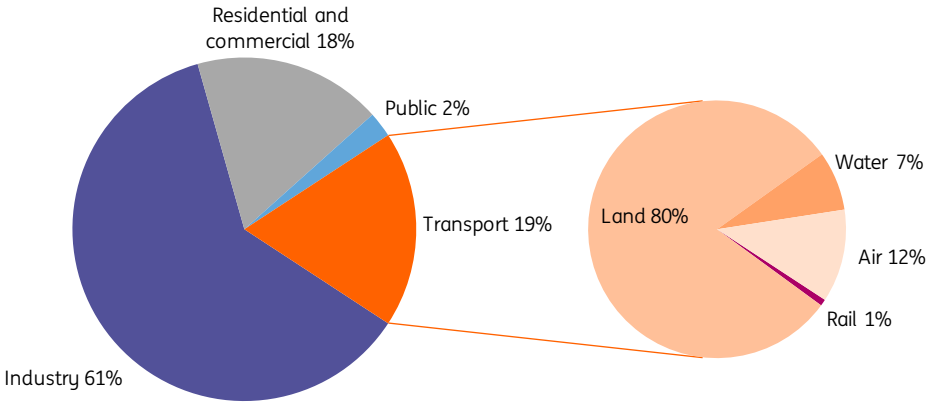
South Korea's total primary energy consumption by fuel type, 2019



Source: BP Statistical Review of World Energy 2020

In 2018, the entire economy energy usage for Korea was 2.7 million GWh, of which transport accounted for only 19%, with industry using the lion's share of 61%. Of this 19%, about 80% was used by Korea's road transport, with rail hardly even registering, and marine and air picking up the difference.

South Korea's energy usage

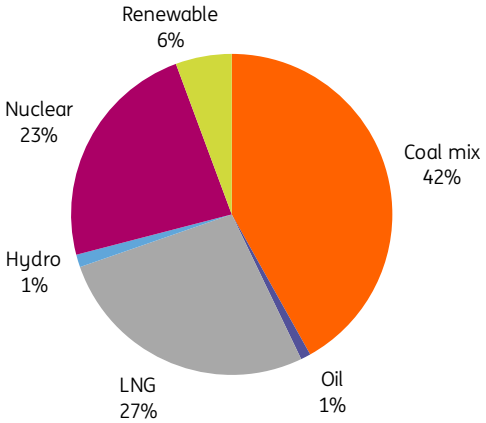


Source: Korean yearbook of energy statistics: 2019

For electricity generation, Korea relies on coal and natural gas for almost three quarters of its generation. A little oil (most of which is imported for use in oil product production (gasoline etc), with 23% of electricity generation coming from nuclear, 1% hydroelectricity and just 6% from renewables and waste[26].

[26] Yearbook of energy statistics, 2019. Korea Energy Economics Institute. http://www.keei.re.kr/web_keei/d_results.nsf/0/3E7B1890D202597E492585150021D4C9/$file/YES2019.PDF

Electricity generation by fuel (GWh)



Source: Korean yearbook of Energy Statistics

The net result of this is that in 2019, Korea emitted about 650m tonnes of CO_2, which is less than the 1.1bn tons Japan emitted, though at about 12 tons per capita per annum, is about 30% more per person in Korea than in Japan[27].

Following its very limited "Green New Deal" announcement in May 2020, in December 2020, the Korean government announced that it would be joining the ranks of other countries aiming for a carbon neutral future with the publication of the chunky yet unimaginatively titled "2050 Carbon Neutral Strategy of the Republic of Korea – Towards a sustainable and Green Society[28]". This is the starting point for the assumed electricity generating mix we use in our subsequent calculations.

However, the 2050 strategy is extremely thin on hard figures, builds in a substantial contribution from fossil fuels though offsets this with considerable reliance on carbon capture and storage. This might well enable Korea to keep some reliance on coal-generated electricity, given that its green technology options are perhaps more limited.

Nonetheless, we get the feeling that the "2050 Carbon Neutral Strategy" should be considered more of a "work in progress" than a fully fleshed-out plan. For example, the talk of green hydrogen fuel cell power generation doesn't sit credibly with expectations for renewable energy by 2040 of only 35% of total electricity generation.

If used, hydrogen fuel cells only fit in the electricity supply mix as storage for surplus renewable energy or as a remote fuel source for off-grid supply. Otherwise, you are simply using renewable energy to create hydrogen, which you then use to produce electricity. This is not a costless round trip and suggests that a great deal more thought is required before we can start taking these official figures more literally. There will be hydrogen demand from transport sectors, but there is no credible incremental energy supply from this source, certainly not without a much more significant contribution from renewable sources.

We have consequently taken inspiration from other sources[29] and applied our estimates for what we think might make sense for Korea.

Our generating mix assumes wind and solar PV generating just under 60% of Korea's electricity by 2050, nuclear 13%, Gas with CC 13%, coal with CC 7%, with the rest picked up by hydroelectric, bio, and ocean power (heat pumps and wave). As before, we have taken our capital cost estimates from the IEA, applied the usual efficiency gains for new

[27] Our World in Data https://ourworldindata.org/co2/country/south-korea

[28] https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf

[29] Long-term energy strategy scenarios for South Korea: Transition to a sustainable energy system Jong Ho Hong et al April 2019 https://www.sciencedirect.com/science/article/pii/S0301421518307936

technology and learning cost reductions to arrive at our 2050 capital cost estimates. But first, we need to calculate the energy needs for transport in 2050.

Korea's electricity generating mix, 2050

	Nuclear	Gas CC	Solar PV	Wind	Coal	Hydro	Ocean	Bio
Korea Prospective weighting	0.13	0.13	0.42	0.17	0.07	0.02	0.04	0.02
Capacity factor	0.85	0.85	0.15	0.265	0.85	0.45	0.45	0.89

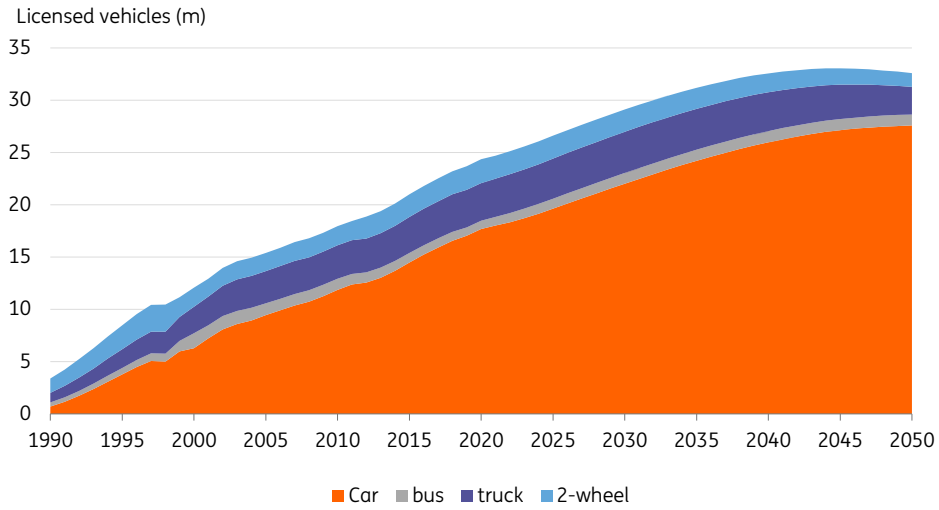
Source: Government of Korea, ING

Road transport

We have less detailed energy consumption data by road transport type for Korea than we had for Japan, and much of this is derived from data on licensed vehicles, which we project to 2050 using assumptions about GDP growth, population, and the relative cost of private transport using variables such as crude oil prices.

These projections differ from those for Japan, showing, for the most part, a substantial rise in road transport though one which begins to top out in around 2040. Most of the gain is in private passenger cars.

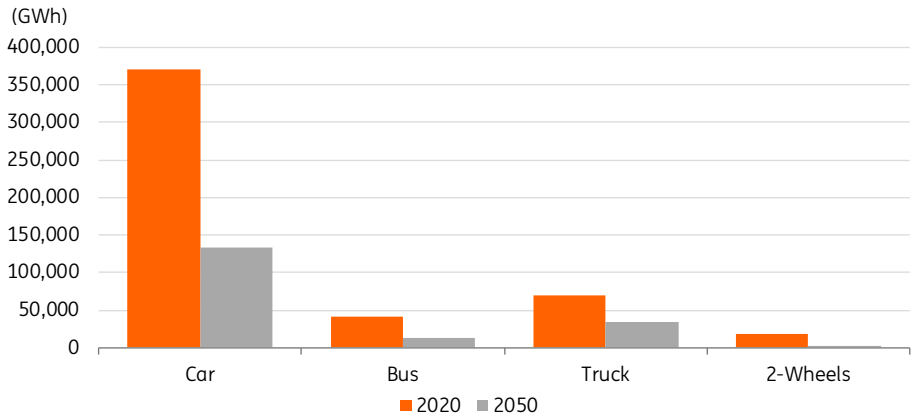
Road vehicle projection



Source: CEIC, ING

Using the same methodology – shows the familiar sight of a distinctly lower energy requirement in 2050 notwithstanding the increase in vehicles, thanks to the efficiency gains of BEVs and smaller gains for fuel cell vehicles (we assume again a 40% take-up for hydrogen fuel cells for trucks, but assume battery electric vehicles elsewhere).

Road transport energy usage 2020 vs 2050 (GWh)



Source: 2050 Carbon neutral strategy of the Republic of Korea Dec 2020

Rail

Rail is a tiny proportion of all the transport used in Korea, and it is almost entirely passenger traffic. Given Korea's geographical location, most goods arrive by sea and air, and the remaining transport of goods to their point of sale takes place by road. With the route north out of Korea effectively closed, there is no realistic prospect of a more significant role for rail transfer in Korea without a route out into China. We don't foresee this happening over our forecast horizon. In any case, it makes little sense to plan for something so unpredictable, and at present, seemingly unrealistic.

President Moon has already pledged to replace all existing diesel passenger trains with electric bullet trains by 2030[30] and claims this will reduce carbon emissions from rail transport by around 30%.

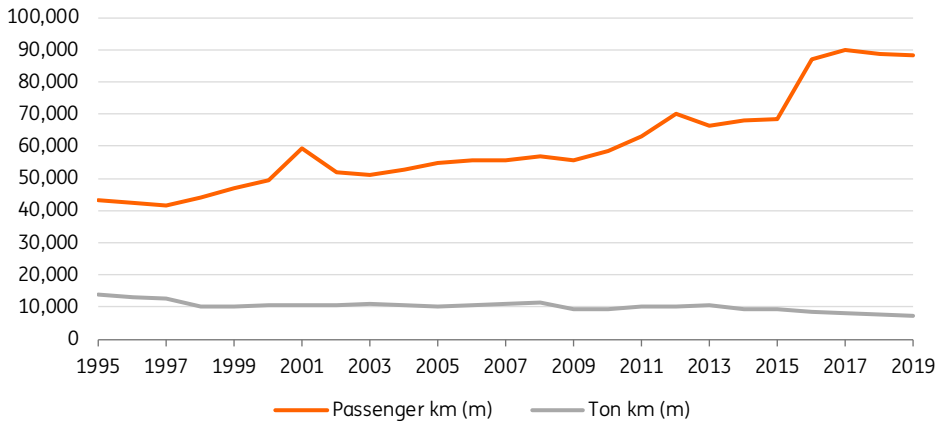
At present, 85% of Korea's rail network is already electrified. So a claim of a 30% reduction of carbon emissions already looks ambitious. The IEA does not believe that a move to high-speed rail will necessarily translate into significant carbon emissions savings, according to a 2019 report[31].

To generate the carbon savings predicted, the new high-speed services must be energy efficient during construction, run on clean electricity, run frequently and near capacity and entice people out of polluting air and road transport alternatives while simultaneously not generating significantly more travel demand[32].

In terms of our calculations, we aren't interested in official claims. Instead, we will focus on a 100% electrified system of rail transport powered by the energy mix we have assumed earlier, with a more significant proportion of renewable energy in production.

Our modelling suggests that rail passenger km travelled will roughly double from 100bn passenger km per year travelled currently. With no changes, this will increase the annual energy usage of rail from 5000GWh to about 10,000 GWh by 2050.

Korean rail traffic



Source: CEIC

With efficiency gains assumed from the electrification of the remaining 15% of the network, what is currently still supplied by diesel, will reduce that total to 7,500GWh (assumes running energy costs per passenger km 70% more efficient than diesel). Allowing for further efficiency gains and offsetting losses due to transmission, we get to an end 2050 figure for rail of 6,933GWh, only a marginal increase over current energy requirements despite a near doubling of passenger km per year. This will require about

[30] "The future of rail" - https://www.iea.org/reports/the-future-of-rail
[31] "The future of rail" - https://www.iea.org/reports/the-future-of-rail
[32] https://www.railway-technology.com/features/high-speed-rail-sustainability/

an additional US$5bn of more capacity installation, of which about US$2.4bn would be for solar PV and US$1.2bn wind power.

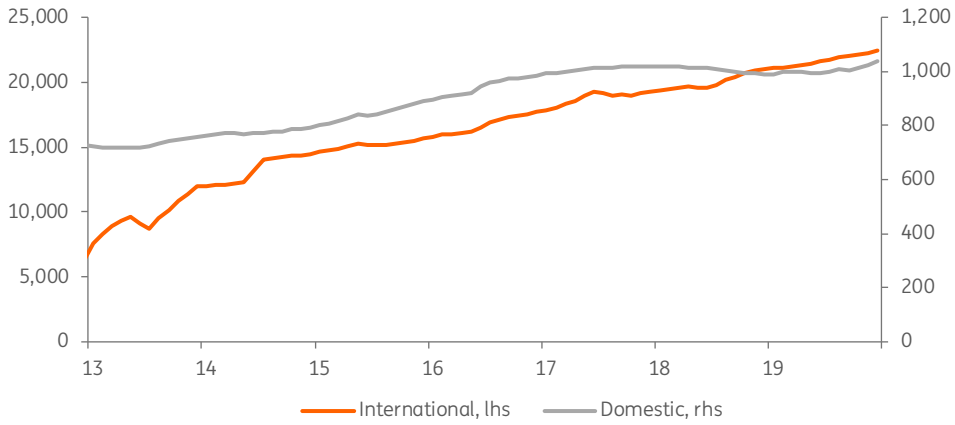
Aviation

Air transport accounts for about 12% of total Korean transport energy consumption and is much more evenly split, with about 60% accounted for by passenger km and 40% by freight tonnage.

Before the global pandemic, passenger transport had been relatively flat, with some tendency for an increase in international travel, but flat domestic travel. Domestic travel is dwarfed by international travel.

Domestic and international air-passenger transport

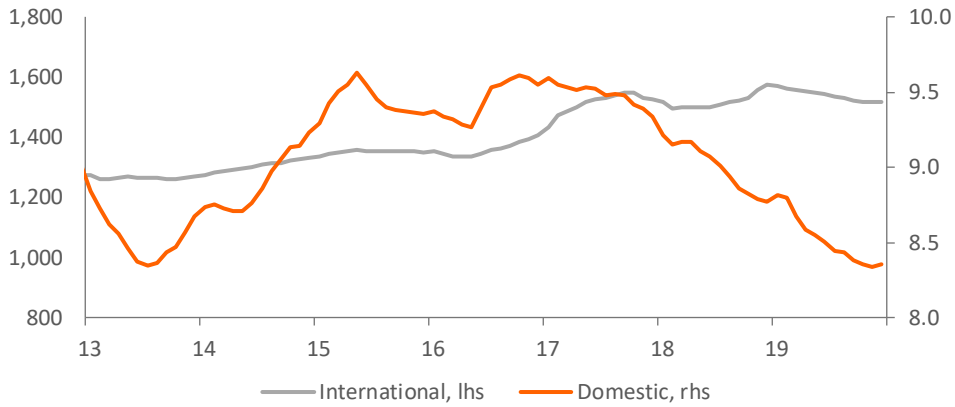
(millions passenger km, 12mma)



Source: CEIC

In the cargo sector, international cargo transport also dominates domestic cargo transport, and before the pandemic, it had been inching higher.

Cargo ton km (millions, 12mma)



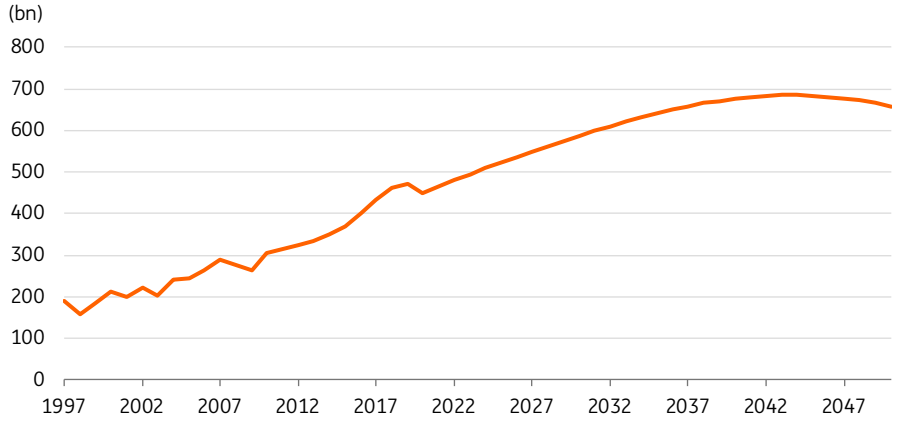
Source: CEIC

With 95% of Korea's passenger transport international and 99% of Korea's cargo transport international, our calculation will assume that domestic aviation moves entirely to rail and road transport.

We assume steady international cargo transport through to 2050 and forecast international passenger traffic subject to the usual parameters of GDP, population, demographics and airline price proxies. We simplify the process with cargo, a fraction of passenger traffic by converting the cargo component to a passenger km equivalent (about 11.1 passenger km = 1 cargo ton km). the resulting forecast shows that, like road

transport, aviation in Korea will see increased demand until about 2040, where it will peak before starting a slight decline.

International aviation passenger km equivalent



Source: ING, CEIC

From the starting point of 2019, energy usage of 35,000GWh, making no other assumptions other than a change in aviation usage by 2050, would see an increase to 48,900GWh by 2050. Allowing for energy efficiency gains reduces this to about 36,171GWh, only slightly increasing over today's energy usage.

We have worked backwards from this as we did for the Japanese example. We have a requirement by 2050 for about 3.8bn litres of sustainable aviation fuel per year, which we calculate would require an additional 17.4GW of additional energy capacity compatible with net-zero carbon. Based on our energy mix assumptions, this would cost about US$31bn in overnight capacity costs – a little more than US$1bn per year over the whole period. But subject to the caveats we made earlier about whether this can be considered net carbon neutral or not.

Marine

Waterborne travel accounts for around 7% of energy usage, of about 35,000GWh. Unlike aviation, almost all of this is for cargo.

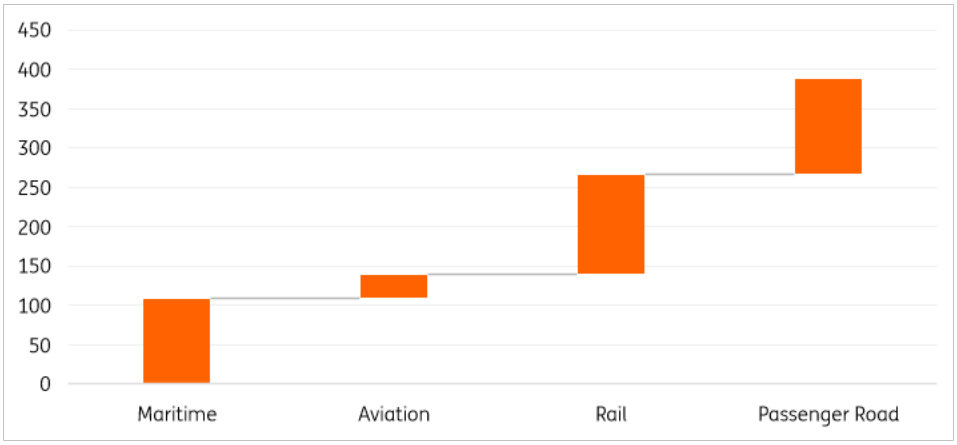
To generate Korea's current maritime energy usage entirely using green energy, assuming a hybrid ammonia combustion/hydrogen gas engine, would need about 28bn litres of ammonia according to our calculations.

Creating this by green processes is relatively energy-intensive, compared to the energy output from ammonia, even when boosted by combusting in the presence of hydrogen. Making this amount of ammonia and hydrogen would take about 166,000 GWh of energy, assuming the process becomes more efficient by 2050, which would need an additional capacity of about 44GW at a total cost of about US$109b or US$3.6bn per year.

Total requirements and costs

If you add up all the components for Korea, there is a much more even distribution of costs than for Japan, which was dominated by marine costs. In Korea's case, the total green energy capacity costs for moving the transport sector towards a net-zero carbon future are about US$400bn.

Additional capital cost required (US$bn)



Source: ING

As before, this estimate does not include any assessment of other infrastructure or fleet replacement, which would likely be at least as large again. But for this simple constrained calculation, we can see that generating capacity costs of about 22% of today's GDP. Over the next 30 years, that amounts to only about 0.6pp of today's GDP per year, and considerably less than this, assuming that GDP keeps growing over this horizon. For Korea, 0.6pp per year is the exact figure we estimated for Japan, which sounds about right.

That is not a small amount of money for just one segment of the economy, but it sounds manageable. If nothing else, it is a sum that shouldn't result in total despair as the estimation has been reached with what we feel are perhaps more realistic and rigorous assumptions than those assumed in official publications.

The current path to net-zero set out in Korea is a pretty broad brush one. On the one hand, it is incredibly encouraging that the ambition to reach net-zero carbon emissions has now been adopted. But over the next one to two years, this path that has until now only been roughly sketched needs to be set out more precisely, and many more concrete actions need to be implemented, not merely discussed. Like both the other economies we have considered, net-zero carbon looks achievable in principle for Korea on the calculations we have performed. But achieving net-zero carbon in practice could slip out of reach if decisive actions are not taken swiftly.

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