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Article title: **Energy Productivity and Decarbonization of the Global Economy: Factor Five Resource Productivity [WENE-217]**

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Abstract

In the 21st Century much of the world will experience untold wealth and prosperity that could not even be conceived only some three centuries before. However as with most, if not all, of the human civilisations, increases in prosperity have accumulated significant environmental impacts that threaten to result in environmentally induced economic decline. A key part of the world's response to this challenge is to rapidly decarbonise economies around the world, with options to achieve 60-80 per cent improvements (i.e. in the order of Factor 5) in energy and water productivity now available and proven in every sector. Drawing upon the 2009 publication *"Factor 5"*, in this paper we discuss how to realise such large-scale improvements, involving complexity beyond technical and process innovation. We begin by considering the concept of greenhouse gas stabilisation trajectories that include reducing current greenhouse gas emissions to achieve a 'peaking' of global emissions, and subsequent 'tailing' of emissions to the desired endpoint in 'decarbonising' the economy. Temporal priorities given to peaking and tailing have significant implications for the mix of decarbonising solutions and the need for government and market assistance in causing them to be implemented, requiring careful consideration upfront. Within this context we refer to a number of examples of Factor 5 style opportunities for energy productivity and decarbonisation, and then discuss the need for critical economic contributions to take such success from examples to central mechanisms in decarbonizing the global economy.

Following significant advances in technology starting in the mid to late 1700s, many were focused on ever expanding development with little concern for the potential future damage to the environment. Apart from a few lone voices such as Svente Arrhenius[1] in the early 1900s that raised concerns for such an eventuality it was considered very unlikely that the activities of industrialising countries could generate enough pollution to affect the entire globe on a meaningful scale. At the time the idea must have sounded ludicrous. However these few voices became many voices by the late 1900s, leading to the build-up of scientific investigation and industry experimentation that has now led to the world entering the 2000s with much of its attention fixed on the issue of reducing pollution from the use of fossil fuels as a matter of urgency, among a number of other pressing challenges.

Long Term Visions Still to be Addressed

Engineers must design more efficient internal combustion engines capable of running on alternative fuels such as alcohol, and new research into battery power should be undertaken… Wind motors and solar engines hold great promise and would reduce the level of CO_2 emissions.

Arrhenius, S. (1926)

In the 1700s if it were possible to comprehend the future impacts of a fossil fuel based system it may have been feasible to take action to reduce such pollution with a global population of less than 700 million people. However, today in a world with over 7 billion people the potential for large scale change in the basis of the energy system is a seemingly overwhelming and complex challenge. Especially considering the tools and strategies that have led to the highly successful fossil fuel based economy may not be as useful to help transition to low carbon operation, and that new tools and strategies may be needed. This highlights the fact that the early part of the 21st century is indeed an era of major transition, one that requires a long term strategic approach.

An Expanding View of Resource Productivity

As the industrial revolution has been taking place now for some 200 years there is significant inertia that, when driven by a market economy to be profitable in the short term, has resulted in very risk averse and narrow sighted economies – which does not present the best approach to dealing with significant challenges on a global scale that will have impacts long into the future, such as poverty or environmental impacts. Even though awareness and understanding of the issue of climate change has been growing in the previous decades still many politicians, business leaders, and members of the public hold the view that nations need to broadly choose between the economy and the environment. In holding this view they miss the reality that by not re-aligning the economy to protect the environment this will significantly undermine the economy in the coming years and decades.

Furthermore, the conditions we are likely to face in the future are set to be quite different from the past. For example, commodity prices have consistently fallen during most of human history, due to improved exploration and exploitation over the past 200 years (The Bank Credit Analyst, 2005). Some people believe that this trend has completely changed since about the year 2000[2], and there are reasons to believe that the successful expansion of resource exploitation may have reached its natural geological limits.[3] It is likely that some resources will now remain scarce and may fetch higher prices for some time to come, such as oil and coal, uranium, indium, lithium, gallium, germanium, cobalt, the platinum group metals, and phosphate. But even if the scarcity grows slower than pessimists assume, all countries are well advised to accelerate their efforts in developing technologies that are dramatically more resource efficient than today's.

Indeed, resource productivity - the amount of economic output that is generated per unit of resource input - is becoming the 'master key' to unlocking numerous barriers to achieving sustainable development. But such development should go much, much further. In a book called *Factor Five*[4], a report to the Club of Rome in 2009, the authors show that a five-fold increase of resource productivity is realizable in the four perhaps most important sectors: buildings, industry, transport, and agriculture. The book, which has its main emphasis on energy and water productivity, depicts many fascinating technologies including cement manufacturing at a fifth of the typical energy requirements; houses like the German *passive houses,* needing one tenth of typical energy; and a combination of crop selection, advanced drip irrigation, and reuse of urban water, leading to a five-fold increase of water productivity in agriculture. Such findings are then supported by valuable guidance as to a range of policy and economic planning issues related to increasing their uptake. The message of the book has been received with strong international interest having been translated into German, Russian, Chinese, French, and Japanese, in just over 3 years.

A key aspect of this growing level of interest is growing evidence that further investigation across a number of systemic levers can lead to the acceleration of economy-wide uptake of low carbon technology and process innovations that can deliver a triad of resource (including energy) productivity improvements, greenhouse gas emission reductions and economic growth. In this paper, we use a focus on the concept of 'stabilisation trajectories' to provide a structure to consider the scale and temporality of energy productivity improvement needs, highlighting short term and long term priorities for decarbonising the economy. In this context we discuss the role of large-scale (i.e. at least Factor 5) energy productivity improvements in delivering a decarbonised economy, and accompanying considerations for a systematic approach to decarbonization.

Looking Beyond Business As Usual

"*Efficient resource use and management is a core goal of economic policy and many fiscal and regulatory interventions that are not normally associated with a 'green' agenda will be involved. And in every case, policy action requires looking across a very wide range of policies, not just traditionally 'green' policies.*"

OECD (2011)[5]

Greenhouse Gas Emissions and Stabilisation Trajectories

It is now well established that increasing levels of greenhouse gas emissions, such as from the combustion of fossil fuels, causes a greater warming of the global atmosphere. Much research has been undertaken to quantify this potential increase, including research published in 2007 in the Journal of Climate indicating that at the time there was a 90 per cent probability that the global temperature would increase by between 3.5 to 7.4 degrees by 2100.[6] Despite such levels of temperature change seeming relatively small research published in the 2006 Stern Review suggested that even small increases in temperature can have dramatic impacts. This poses a significant challenge as fossil fuels have been the basis for economic development for many decades, and are responsible for an estimated 78 per cent of the world's greenhouse gas emissions.[7]

Stern Review Findings on Temperature Change

The Stern Review suggests that just 1°C degree is likely to lead to *'80% of coral reefs are bleached*', a 2°C rise likely to lead to lead to '*Crop yields in Africa drop by 5% - 10%*', a 3°C rise likely to lead to '*In southern Europe, serious drought happens occurs every 10 years*', 4°C rise likely to lead to '*Water availability in Southern Africa and Mediterranean could drop by 30% - 50%*', and '*African agricultural yields drop by 15% - 35%*', and a 5°C rise likely to lead to '*Sea level rise threatens small islands, low-lying coastal areas such as Florida, (Florida) and major world cities such as New York, London, and Tokyo*'.[8]

Hence there is an imperative for a global effort to rapidly reduce greenhouse gas emissions that will involve a shift away from the use of fossil fuels. Since 1988 the Intergovernmental Panel on Climate Change (IPCC) has released a series of assessment reports that have informed global debate and shaped understandings around the seriousness of the climate change situation. Dr Rajendra Pachauri, the IPCC Chairperson articulates the severity of the situation in his foreword to the textbook *Cents and Sustainability*,[9]

> '*The increased evidence of abrupt changes in the climate system, the fact that CO_2 equivalent levels are already at 455ppm, plus the current high rate of annual increases in global greenhouse gas emissions reinforces the IPCC's 4^{th} Assessment finding that humanity has a short window of time to bring about a reduction in global emissions if we wish to limit temperature increase to around 2^oC at equilibrium. The IPCC's 4th Assessment calls for global greenhouse gases to peak no later than 2014-15 and to rapidly decrease after that to 80 per cent below 1990 levels by 2050 to achieve this'.*

Research undertaken as part of the IPCC's Fifth Assessment Report in 2014 suggests that the 2^oC goal can be achieved with '*high confidence*' if by 2100 GHG levels stabilise at 450ppm. However it is '*more likely than not'* to be achieved at stabilisation levels of about 500ppm, '*more unlikely than likely'* at levels of 530 to 650ppm, and '*unlikely*' at levels about 650ppm.

The key to an ambitious approach to GHG emissions reduction is to achieve a balance in the timing of the peaking of emissions (with no more growth in emissions in the short term) and the corresponding tailing off of emissions annually to reach the target level (over a number of decades). The combination of a 'Peak' and corresponding 'Tail' creates what Stern (2006) refers to as a 'Stabilisation Trajectory', with each trajectory having a different impact on the economy. In effect, a late peak would allow a more relaxed approach in the short term but then greater efforts later to meet the overall target. Alternatively an early peak would require concerted effort through rapid short term reductions, but then more relaxed efforts (i.e. more flexibility) in the longer term to reach the end-goal.[10]

For example, when considering a target of 500ppm there are a number of peaking and tailing combinations that stand to achieve this level of greenhouse gas stabilisation however those that involve a delayed peak also involve more stringent annual reductions. As Figure 1 shows in both the 2020 and 2030 peaking scenarios if the peak is allowed to rise at current levels the resulting tail is much steeper to achieve the stabilisation level. For instance '2030 High Peak' curve shows a requirement of 4.5 per cent annual sustained reduction, compared to the '2030 Low Peak' curve which shows a requirement for 2.5 per cent per annum. The *Stern Review* points out that, *'Given that it is likely to be difficult to reduce emissions faster than around 3% per year, this emphasises the importance of urgent action now to slow the growth of global emissions, and therefore lower the* *peak.'*[11] Following this argument, a target trajectory that involves a 2020 peak or at least a 2030 low peak is preferable from an economic stand point.

Figure 1: Illustrative emissions paths to stabilise at 550ppm CO_2e[12]

In order to compliment goals for the overall reduction of greenhouse gas emissions, such as 80 per cent by 2050 compared to 1990 levels, goals related to annual reductions will be required. An early leader in this area is the Chicago Climate Exchange that in 2005 attracted the likes of DuPont, ST Microelectronics, Baxter Health Care, the City of Chicago, Natural Capitalism Incorporated and 12 other businesses to adopt contractual requirements to reduce emissions by a minimum of 1 per cent a year. Just three years later the exchange membership had grown to 330 with new members required to reduce their emissions by a minimum of 2 per cent a year.[13] Other examples include Salt Lake City's goal to reduce greenhouse gas emissions by 3 per cent per year for a 10 year period.[14]

In summary, stabilisation trajectories provide structure to assess various technology and process innovations to derive either short term peaking or long term sustained reductions (i.e. tailing). Considering the 'sustained reductions' model, this approach allows a focus on already abundant opportunities for short term reductions to achieve the peak, while at the same time developing the experience and economies of scale to address the issue of long-term sustained reductions. [15] This also creates time for economies to stage out activities where certain industries, or even nations, may be given more time, or 'head room', to respond.

Stern Review Recommendations for Action on Peaking and Tailing

'*It will be cheaper, per tonne of GHG, to cut emissions from some sectors rather than others because there will be a larger selection of better-developed technologies in some… However, this does not mean that the sectors with a lack of technology options do nothing in the meantime. Indeed, innovation policies will be crucial in bringing forward clean technologies so that they are ready for introduction in the long term.'* [16]

Decarbonising through Technology and Process Innovations

When considering specific technologies to contribute to peaking and tailing of emissions the Stern Review suggests a portfolio for each as shown in Figure 2. Stern includes both nuclear power and biofuels as options, however both have significant social, environmental and economic issues, and there is abundant research to demonstrate that such energy sources will not be needed.[17]

Figure 2: An Illustrative distinction between carbon abatement options contributing to short-term peaking of emissions, compared to a sustained reduction of emissions over time. (*Source*: Stern, 2006)

In order to respond to the challenge of climate change a strong case needs to be presented to show that significant reductions in the energy consumption of our economies can not only be achieved, but can be achieved cost effectively and in a timely manner.[18] When considering a design solution there are a range of ways to reduce the greenhouse gas emissions intensity of the design, construct, operation, and decommissioning stages, across all major sectors – See Table 1.

Table 1: *Example opportunities to significantly reduce greenhouse gas emissions over the last 15 years*

In researching these examples and other technical components of the 2010 book 'Factor Five'[19] it became apparent that in each of the successful examples a common set of questions had been considered, namely:

- *Is the current method of delivering the product or service the only way to do so*? Often the first thought when answering this question is 'yes', however, further investigation can lead to a range of alternatives - from system upgrades, such as energy efficient motors in an industrial application, to completely new processes, such as shifting to a process to predominantly use scrap metal rather than processing primary resources to make steel.
- *If it is the only way, a) what are the major areas of energy, water and materials usage, b) what options are available to reduce the need for such inputs, and c) what alternatives are available to provide these inputs?* The search for such alternative options and inputs can be driven by a requirement to reduce environmental impacts, but also as part of a strategy to improve competitive advantage by reducing input costs, which are inevitably set to increase in the future as availability and impact are factored in.
- *If it is not the only way, what alternatives to the system currently used can be used to profitably deliver the product or service with less resource intensity and environmental pressure?* For instance, geo-polymers can be used to create cement with as much as 80 per cent less energy intensity, partly by eliminating the process emissions of greenhouse gases associated with Portland cement production.

When considering strategies to support such a pragmatic enquiry once the initial questions as to the best way to meet the design requirement have been answered, the system then needs to be benchmarked against best practice in order to understand the potential for performance improvements. However, in many cases the new design concept will be part of an emerging wave of innovation and hence there may be little precedent to provide a benchmark. Further, even if there are established examples of the new design, such processes and methodologies are unlikely to have had time to be incorporated into industry practice or into university or professional development courses.

Accelerating progress

A critical barrier to current efforts in improving energy productivity is that designers, engineers, architects and technicians are not widely versed in taking a systems based approach to design. The reality that the engineering and design professions now face is that even with significant advances being made by designers across the world, the shift from an incremental approach to a systems approach is in its early stages, largely *ad hoc* and champion based.[20,21] Such capability-based barriers are problematic but there is movement towards curriculum renewal as documented by the first two authors in the 2014 publication *"Higher Education and Sustainable Development: A Model for Curriculum Renewal"*.[22]

The book 'Factor 5' observes that progress in the spreading of efficiency remains painfully slow for another straightforward reason: Governments consistently want to please by making natural resources as cheap as possible, frustrating efforts towards higher resource productivity. Consequently, resource productivity has received attention only when acute crises have made resources scarce and expensive. By and large, the option to artificially create a financial signal of *future* scarcity has been overlooked as an economic development strategy. Notable exceptions are China and Germany. China first let energy prices, which were formerly heavily subsidized, gradually approach world market levels and later even moved them upwards beyond the world market. Germany, in 1999 introduced tax reforms that shifted an increasing part of the fiscal burden from labour to energy thus making energy efficiency more profitable and the laying off of workers less.

A now well understood and practiced method of putting a price on energy use, or more specifically, on the emission of CO_2 or other greenhouse gases, through the limiting and trading of emission permits. This has been the method chosen by the EU countries for fulfilling obligations under the Framework Convention on Climate Change (FCCC) and its Kyoto Protocol. However, the emissions trading system (ETS) faced an unanticipated challenge with prices for the permits fell to near zero, due in part to the designers of the system under-estimating the strong response from business to create credits.

The key to pricing emissions is to create a predictable trajectory as this can be very attractive for investors and creators of new technologies. They can more or less calculate, by what time an efficiency technology will become profitable. This is one of the key proposals presented in *Factor Five:* to make energy prices (and raw material prices) rise across a sector or economy by as much as the average documented efficiency gains in that sector or economy the previous year. Then, on average, the cost of buying energy and materials remains constant, with those underperforming compared to the average paying more and those outperforming the average paying less.

The basic inspiration to such a strategy comes from looking at the highly attractive story over 150 years or more of human labour productivity always rising in parallel with gross labour cost. Figure 3 shows a time window from the US, but very similar pictures exist for other countries. Over a period of 150 years, both labour productivity and gross labour cost rose roughly twentyfold in the successful industrialized countries.

Figure 3: Real compensation and labour productivity for the non-farm business sector in the US between 1960 and 1995. (*Source*: Presented in von Weisaecker, et al (2009) and based on data from the Department of Commerce, Department of Labor, and Council of Economic Advisers)

This mutually enforcing development of cost and productivity turned out to be the engine of technological progress and of spreading wealth. The idea of copying this success story and moving resource prices up in line with gains in resource productivity was first articulated well in the context of a Task Force on economic instruments in the China Council for International Cooperation on Environment and Development (CCICED), publishing their report in 2009.[23] To avoid hardship for poorer strata of society, some low price base line can be accepted, partly because technological progress tends to arrive at poorer families later than at the rich. The system of predictably and gradually rising energy and resource prices would constitute a very strong incentive for long term strategies of using the respective commodities ever more efficiently.

Within this context, strategies and policies to achieve stabilisation trajectories will no doubt dominate national economic development strategies in the coming decades. Rather than there being ‘right’ or ‘wrong’ pathways for progress towards decarbonising economies, the critical aspect is deciding the temporality of peaking and tailing, and subsequent upfront planning addressing embedded complexities in the decarbonising process. In addition to skills development and financial considerations discussed already, support for economic growth and significant reductions in greenhouse gas emissions could also involve:

- *Minimum Performance Standards*: Including regulation and policy designed to drive industry to take innovative approaches to reducing greenhouse gas emissions, while capitalising on this innovation in the world market in the form of carbon trading or increased exports in technologies and expertise.
- *Financial Mechanisms*: Shifting the focus of taxation to resource taxation that places an additional price on the use of resources that result in undesired environmental and social impacts that will have a direct impact on economic growth. According to Hawken *et al*, long time advocates of this approach, '*Shifting taxes towards resources creates powerful incentives to use fewer of them.'*[24]
- *Research and Development*: Investing in research and development of low carbon technologies and processes supported by industry to provide viable low carbon outcomes.
- *Voluntary Programs*: Providing assistance to industry and business to uptake low carbon technologies and practices in collaboration with industry groups.
- *Skills Development*: Creating opportunities to enhance secondary and tertiary industries with such commodities to allow greater value adding and increased wealth generation through increased exports of low carbon technologies and expertise.
- *Behaviour Change*: Supporting communities to reduce fossil fuel demand in a way that delivers energy cost savings, reducing the economic burden from energy.
- *Curriculum Renewal*: Supporting a comprehensive renewal of higher education to align it with the goal of achieving economic growth and a significant reduction in greenhouse gas emissions.

Such levels of complexity call for a systemic approach that focuses on multiple leverage points across the economy. However there are very few examples of intentional processes that have achieved such wide spread outcomes in short periods of time. Perhaps the closest example is that of war-time urgency with WW2 having a significant impact on the US economy involving a near complete retooling of many industries to the war effort in a very short period of time.

> *In the period 1939–1945, unemployment in the USA fell from 14.6 per cent to 1.9 per cent, and GDP grew 55 per cent. In 1942 US economic growth was 12 per cent - that is 12 times more than in the 2007-8 financial year. Wages grew 65 per cent over the course of the war to far outstrip inflation, and company profits boomed, all at a time when personal consumption was dampened by the sale of war bonds, some basic goods and foods were rationed, and at the height of the mobilisation 42 per cent of the economy was directed towards the war effort.* (Smith and Hargroves 2010)

However unlike the threat of war, or the need for post war reconstruction, which are both immediate and aimed at the powerful, the threat of climate change is less immediate, uncertain, and will play out over decades, typically affecting the poor and vulnerable first. A potentially more useful example of economy wide changes in a short period of time is that of conditional lending by the IMF and the World Bank, creating 'Structural Adjustment Programs'. Fundamentally the term 'Structural Adjustment' can be interpreted as the process of making system wide changes to the very structure of an economy, typically through government policy, to improve its performance. Such changes are typically driven by an intention to improve the economic performance of the economy in a response to a need to reduce debt or position itself to replay development loans.

Conclusion

The concept of factor improvements is not new – from Factor 4 discussions in the mid-nineties, through to Factor 5 and even Factor 10 discussions today. What has improved is an increased awareness of the connections and multiple benefits in addressing energy efficiency, resource productivity, and decarbonisation strategies together. Furthermore, there is an improving appreciation of the embedded complexities in realising the concepts, and in mainstreaming the potential improvements in resource productivity.

Looking ahead, there is the potential for long term but revolutionary improvement of resource productivity, affecting all parts of the economy and addressing challenges to environmental policy makers with regard to previously seemingly intractable factors such as infrastructure planning, housing, mobility habits, nutrition habits, and the durability of goods. Assuming that world-wide scarcities or the cost of refinement will eventually be felt in all economies, it can be expected that countries that introduce the efficiency technologies first would benefit and would enjoy lots of "first mover advantages" on the world markets.

Moving forward, there are a number of immediate issues to be addressed, related to marrying cost and productivity incentives for long term strategies in using commodities more efficiently. Further, such interventions by government and the market need to be founded on a clear understanding of greenhouse gas emissions peaking and tailing intentions, to create a systematic approach to improving resource productivity that can also be transformative in decarbonizing economies. In the same way that fiscal structural adjustment was formulated as a solution to underdevelopment in third world economies in the 20th century, a new form of structural adjustment, '*carbon structural adjustment*', may need to be formulated as a solution to unsustainable development around the world in the 21st century.

Further Reading/Resources

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Tables

Table 1: *Example opportunities to significantly reduce greenhouse gas emissions over the last 15 years*

Sector	Best Practice Case Studies
Steel Industry[25]	Leading US steel company, Nucor Steel, is around 70% more energy efficient than many steel companies around the world,[26] using state-of-the-art electric arc furnace systems, adopting leading practices such as net shape casting, and by implementing options such as energy monitoring, systems for energy recovery and distribution between processes.[27]
Cement Industry[28]	Ordinary Portland cement manufacture is responsible for between 6-8% of global greenhouse emissions and this is rising with demand. The good news is that an Australian company Zeobond Pty Ltd, based in Melbourne, is now making geo-polymer cement which reduces energy usage and greenhouse gas emissions by over 80%.[29] Geo-polymers can be used for most major purposes for which Portland cement is currently used.[30]
Paper and Pulp Industry[31]	Catalyst Paper International has improved their energy efficiency by 20% across all operations since 1990, saving the company close to US$26 million between 1994 and 2004. At the same time, they've reduced their greenhouse gas emissions by 69% through greater use of biomass and sourcing electricity from hydro power.[32] The pulp and paper sector has the potential in both existing and new mills to become renewable electricity power generators through the use of Black Liquor Gasification-Combined Cycle (BLGCC) technologies.[33]
Data Centres[34]	Google has achieved 80% energy efficiency improvements in its data-centres through efficient data centre design, efficient power supplies and efficient voltage regulator modules on motherboards.[35] Unnecessary components, such as graphics chips, are omitted. Fan energy is minimised by running fans only as fast as required. Finally, Google seeks to use components that operate efficiently across their whole operating range, a strategy that the company estimates could reduce data centre energy consumption by half.[36]
Super-markets[37]	Supermarket chains Tesco (UK) and Whole Foods (USA) are showing that there are numerous ways to significantly reduce electricity usage through for instance reducing cooling and heating loads and utilising more efficient lighting.[38] They are also experimenting with solar energy and wind micro-turbines.[39] Whole Foods Market are set to power an entire store using solar panels and a combined cycle co-generation using fuel cells and heat recovery.[40]
Restaurant[41]	Four profitable restaurants – Bordeaux Quay (Bristol, UK),[42] Foodorama (Berlin, Germany),[43] The Acorn House (London, UK)[44] and The Water House (UK) – demonstrate that restaurants can significantly reduce their energy consumption through building design, energy efficient lighting and cooking equipment, purchasing their electricity from accredited renewable sources, buying organic fresh local food in season, composting and recycling all waste, and investing in carbon offsets.
Transport – Vehicle Efficiency[45]	Integrating technical advances in light-weighting, hybrid electric engines, batteries, regenerative breaking and aerodynamics is enabling numerous automotive and transport vehicle companies to redesign cars, motorbikes, trucks, trains, ships and aeroplanes to be significantly (50-80%) more fuel efficient than standard internal combustion vehicles. Plug-in vehicle technologies are opening up the potential for all transportation vehicles to be run on batteries charged by renewable energy.[46]
Transport – Efficiency from Modal shifts. (Passenger)[47]	Shifting transport modes can also lead to significant energy efficiency gains. One bus with 25 passengers reduces energy and greenhouse gas emissions per capita by approximately 86% per kilometre compared to 25 single occupant vehicles (SOV).[48] Trains are even more efficient. Typically, rail systems in European cities are 7 times more energy-efficient than car travel in US cities.[49]
Transport Efficiency from	Shifting freight transport from trucks to rail can also lead to large efficiency gains of between 75 and 85%.[51] Several countries are moving to improve the efficiency of their

Modal Shifts (Freight)[50]	transport sectors by making large investments in rail freight infrastructure, including improving the modal interfaces. For instance, China has invested US$292 billion to improve and extend its rail network from 78,000 km in 2007, to over 120,000km by 2020, much of which will be dedicated to freight.

Source: Edited from von Weizsäcker, Hargroves, K. *et al* (2009)[52]

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