



## Energy and Health 3

### Energy and transport

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#### Summary

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This is the third in a **Series** of six papers about energy and health

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We examine the links between fossil-fuel-based transportation, greenhouse-gas emissions, and health. Transport-related carbon emissions are rising and there is increasing consensus that the growth in motorised land vehicles and aviation is incompatible with averting serious climate change. The energy intensity of land transport correlates with its adverse health effects. Adverse health effects occur through climate change, road-traffic injuries, physical inactivity, urban air pollution, energy-related conflict, and environmental degradation. For the world's poor people, walking is the main mode of transport, but such populations often experience the most from the harms of energy-intensive transport. New energy sources and improvements in vehicle design and in information technology are necessary but not sufficient to reduce transport-related carbon emissions without accompanying behavioural change. By contrast, active transport has the potential to improve health and equity, and reduce emissions. Cities require safe and pleasant environments for active transport with destinations in easy reach and, for longer journeys, public transport that is powered by renewable energy, thus providing high levels of accessibility without car use. Much investment in major road projects does not meet the transport needs of poor people, especially women whose trips are primarily local and off road. Sustainable development is better promoted through improving walking and cycling infrastructures, increasing access to cycles, and investment in transport services for essential needs. Our model of London shows how increased active transport could help achieve substantial reductions in emissions by 2030 while improving population health. There exists the potential for a global contraction and convergence in use of fossil-fuel energy for transport to benefit health and achieve sustainability.

#### Unsustainable transport

Motorised transport is over 95% dependent on oil and accounts for almost half of world use of oil.<sup>1</sup> Greenhouse-gas emissions from transport are projected to continue to rise rapidly (figure 1).

Transport is the only sector of the UK economy for which current emissions are higher than in 1990. Direct emissions from personal vehicles rose from 59 million tonnes of carbon dioxide in 1990 to 63 million tonnes in 2002, an increase of 6%. In the same period, emissions from heavy goods vehicles increased by 48% (from 16 to 23 million tonnes) and from shipping by 25% (from 12 to 15 million tonnes).<sup>2</sup>

In western Europe, freight transport has more than doubled since 1970 to about 3000 billion tonnes km, with road and short sea-shipping taking the largest shares (44% and 41%, respectively). In eastern Europe, the 1990s witnessed a major decline in rail transport and a concurrent increase in car and truck use. In the USA, passenger-car emissions increased by 2% from 641 million tonnes in 1990 to 655 million tonnes in 2003. Emissions from light-duty trucks, increasingly used for passenger transport, rose by 51% from 323 to 496 million tonnes, and those from medium-duty or heavy-duty trucks rose by 57% from 218 to 343 million tonnes.<sup>3</sup>

Tail-pipe emissions are only part of a motor vehicle's contribution to climate change. Over the vehicle's lifecycle, emissions are generated during extraction of raw materials and movement, production, and disposal. These emissions are estimated to add 18–43% to tail-pipe emissions.<sup>3</sup> Additionally, transportation infrastructure

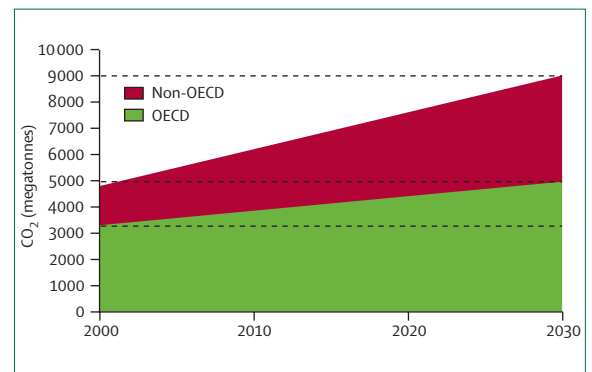


Figure 1: Projected growth in transport emissions of carbon dioxide to 2030<sup>1</sup>

#### Key messages

- The adverse health effects resulting from climate change, road-traffic crashes, physical inactivity, urban air pollution, energy insecurity, and environmental degradation are linked via their common antecedent of fossil-fuel energy use in transport
- Public policies that encourage a transition to a low-carbon low-energy transportation system have the potential to bring substantial public-health benefits by affecting all these health pathways
- Increased active transport (walking and cycling), with public transport for longer journeys, could have a substantial role in meeting targets for greenhouse-gas emissions and would result in major public-health benefits

requires energy for construction and maintenance. Furthermore, transport facilitates changes in land use, enabling deforestation and thus reducing the earth's ability to absorb carbon dioxide.

Although transport emissions are rising faster in low-income and middle-income countries than in those with high income, there remain massive global inequalities in transport energy use both between and within countries. In 2003, global average consumption of petrol and diesel was 283 L per person per year, ranging from about 12 L per person per year in Nepal, Bangladesh, and Ethiopia to 2135 L per person per year in the USA.<sup>4</sup> Walking remains the main mode of transport for the poor in most countries.

Attention is increasingly focused on China, with a fifth of the global population and rapid economic growth, and where consumption of petrol for transport nearly doubled between 1990 and 2003.<sup>5</sup> Although still substantially below per-head distances in high-income countries, total motorised passenger-km rose six-fold between 1980 and 2003, and freight distance increased nearly five-fold.<sup>6</sup> Rapid urbanisation and motorisation have seen road space for cycling curtailed. The number of cars and sports-utility vehicles in China could increase 15-fold over the next 30 years to over 190 million, with carbon dioxide emissions from transport increasing more than three-fold (figure 2 and figure 3),<sup>7</sup> a situation that would be environmentally unsustainable. However, expecting lower-income countries to change trajectory while transport emissions in rich countries continue to rise from much higher levels is unreasonable.

Aviation is increasing and has a large effect on climate change. In 2001, the Intergovernmental Panel on Climate Change (IPCC) estimated that aviation caused 3·5% of human-induced global warming, which could rise to 15% by 2050. In 2003 there were 1·6 billion trips by passengers worldwide and, by 2010, this figure could exceed 2·3 billion. The UK has the highest air travel per head in Europe, with a fifth of international flights passing through UK airports. According to the UK Civil Aviation Authority, passenger numbers at UK airports have been growing at about 6% per year since the mid-1970s—more than twice the rate of economic growth—and show no sign of slowing. The UK Department of Transport estimates that aviation contributes about 5·5% of UK carbon-dioxide emissions, but about 11% of the UK's total effect on climate change. The UK's share is calculated by allocating emissions from half the flights to and from UK airports to the UK, but more than half of these flights are by UK citizens. Therefore, at the household level, the contribution of flying is higher and could be greater than from driving.<sup>8,9</sup> Recent studies estimate that by 2030 UK total aviation emissions of carbon dioxide will rise from 32 million tonnes in 2000 to 65–85 million tonnes.<sup>10</sup> These predictions include probable gains in efficiency.

Most of the increase in UK flights has come from

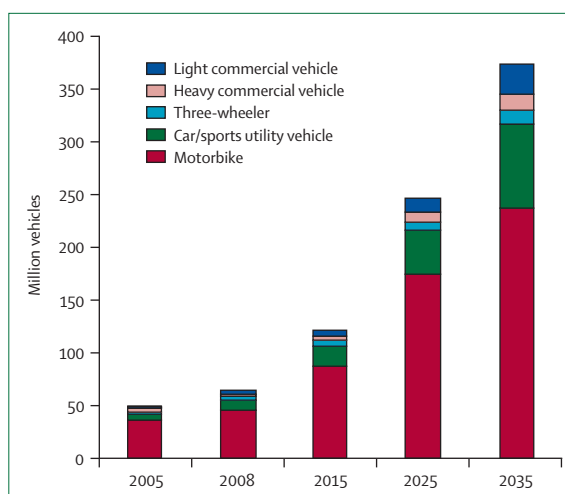


Figure 2: Vehicle populations forecast in China<sup>7</sup>

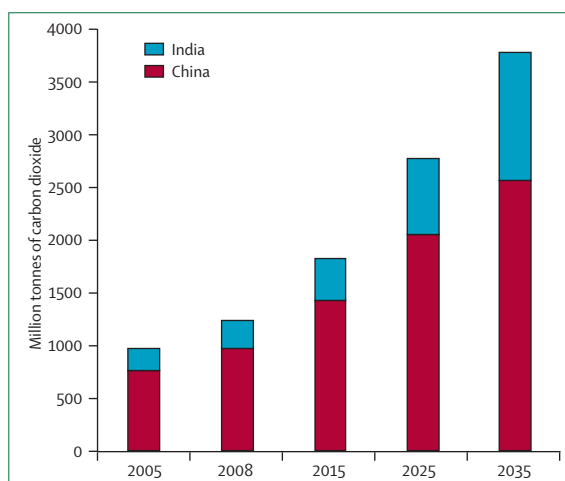


Figure 3: Total carbon dioxide emissions (well to exhaust) from on-road vehicles: India and China<sup>7</sup>

wealthier individuals flying more. Trips by those in the lower-income bands fell between 2000 and 2004.<sup>10</sup> Even with cheap flights, foreign holidays remain too expensive for those on low incomes. The average household income of UK leisure passengers travelling through Stansted airport was £51000 in 2005, according to the Civil Aviation Authority's 2005 Passenger Survey Report,<sup>11</sup> compared with an average household income of £31000. A survey of emissions in the UK, including all transport modes, found that the top 10% of emitters produced almost 43% of emissions whereas the bottom 10% produced only 0·1%.<sup>9</sup>

Aviation is believed to have a greater effect on climate change than its carbon emissions alone. Additional contributors include nitrogen oxides, soot, sulphate particulates, and water vapour, which lead to the formation of contrails and cirrus clouds at altitude. Cirrus cloud formation is difficult to predict and model. The effects of nitrogen oxides and water vapour vary by

altitude and weather conditions. Nitrogen oxides have conflicting effects, both destroying ambient methane, but producing ozone, with a changing balance between the two effects with time.

Recent estimates suggest that the effect of aviation on climate change is 1.9 times greater than that which would be due to its carbon emissions alone.<sup>12</sup> However, there is still considerable uncertainty about the size of this effect, and care must be taken in its application. First, cirrus cloud changes are excluded as too uncertain to estimate. Second, other activities produce non-carbon greenhouse-gas emissions. Third, this estimate is based on the historical effect of emissions on climate change and not the effect of current or future emissions on climate.<sup>10</sup> Non-carbon-dioxide emissions have a shorter-term effect than does carbon dioxide, which remains in the atmosphere for 100 years or more. Thus in 1 year the climate-forcing effect of a flight could be 36 times the carbon emissions but this would fall to 3.7 times over 20 years.

Because the effect of aviation is greatest in the short term, controlling aviation becomes increasingly important as climatic thresholds are reached. Moreover, just as the need for car travel is now built into the fabric of cities and into the economic and social lives of citizens, so increasingly is aviation, with airport expansion and the purchasing of second homes overseas by the richer residents of affluent countries.

### Transport, energy, and health

Some of the links for land transport are shown in figure 4.

### Injuries

The energy intensity of road vehicles is reflected in their effects on health. Because of the growth in traffic, many people are exposed to levels of kinetic energy that can and do result in serious injury. The WHO World Report on Road Traffic Injury Prevention estimated that 1.2 million people were killed and 50 million people injured in road-traffic crashes in 2002;<sup>13</sup> these figures continue to rise. Still a neglected epidemic, injuries are among the leading causes of disease burden in developing countries, with the highest regional road-death rates in Africa (28 per 100 000 per year), and the highest national rates in El Salvador (42 per 100 000 per year) and the Dominican Republic (41 per 100 000 per year). In addition to physical injury, mental health can be affected by post-traumatic stress disorder.

Per kilometre travelled, heavy goods vehicles are twice as likely to be involved in fatal crashes than are cars. In most settings, those at greatest risk are people on low incomes who do not have the option of car travel and often have to walk long distances on roads carrying high-speed vehicles. Public transport systems can be extremely safe; however, in many low-income countries such services are underdeveloped and poorly run informal services pose a high risk to passengers and other road users.<sup>13,14</sup>

34% of deaths of children due to injury in the European Union (EU) are caused by road crashes and the distribution of these injuries varies greatly by country. Death rates from road collisions in Portugal, Lithuania, Estonia, and Latvia are almost six times greater than those in Malta, Sweden,

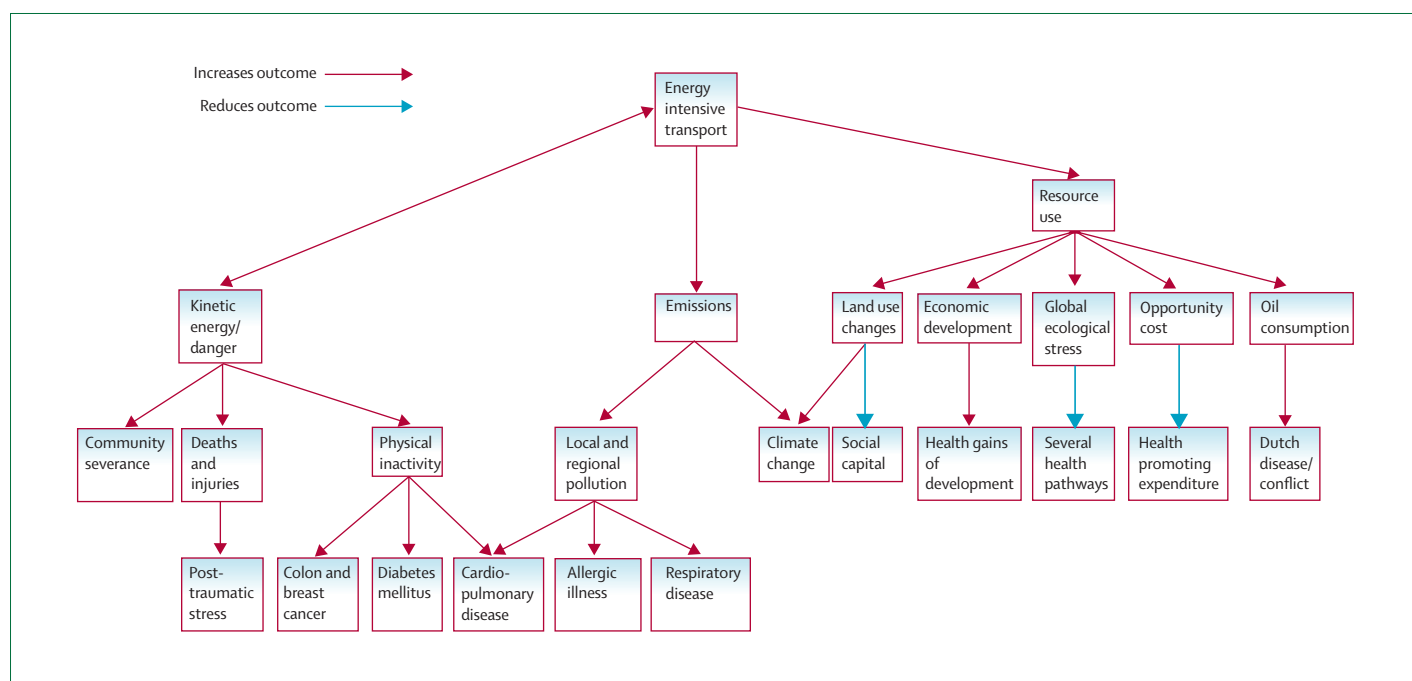


Figure 4: Selected pathways between transport and health

and the UK.<sup>15</sup> Child pedestrians are at high risk in the UK, with twice the rate of injury seen in France or Germany.

Walking and cycling become safer when they are more common, so increasing active travel can improve its safety.<sup>16</sup> The World Report on Road Traffic Injury Prevention argues for a systems approach to injuries.<sup>13</sup> The vulnerability of the human body should be the system limit and speed management is considered essential. Systems need to accommodate common behaviours without leading to death and serious injury. Therefore, prevention strategies should prioritise vulnerable road users by requiring motorised traffic to anticipate the variation in walking and cycling behaviour, and by limiting the speed and volume of motorised traffic. Evidence-based recommendations include alcohol control, changes to vehicle fronts, reduced hours for lorry drivers, speed enforcement, and traffic calming.<sup>13</sup>

### Physical inactivity

Road danger is a disincentive to active transport, which creates a vicious circle. Over the past century, oil has increasingly displaced food as the energy source for human movement. At the same time, occupational and domestic physical activity have fallen. Replacement of short trips in cars by walking or cycling would enable most motorists to achieve recommended levels of physical activity. Public transport trips usually include a walking component, and hence greater physical activity than car trips. The Global Burden of Disease Study estimated that physical inactivity is responsible for 3·3% of deaths and 19 million disability-adjusted life-years (DALYs) worldwide, through diseases including ischaemic heart disease, diabetes, colon cancer, stroke, and breast cancer.<sup>17</sup> There is evidence of an independent effect of physical inactivity and weight on the risk of diabetes.

The prevalence of type 2 diabetes in urban adults in India is reported to have increased from less than 3% in 1970 to around 12% by 2000.<sup>18</sup> Cardiovascular disease accounts for 27% of deaths in low-income countries; by contrast, HIV/AIDS, tuberculosis, and malaria, combined, account for 11%.<sup>19</sup> In these countries, cardiovascular disease often occurs at younger ages than in higher-income countries.<sup>20</sup>

Because food-energy intake has not decreased in line with reductions in physical activity, many countries are experiencing an epidemic of obesity. A survey in Atlanta, GA, USA, found that each additional hour spent in a car per day is associated with a 6% increase in the likelihood of obesity.<sup>21</sup> According to the Global Burden of Disease Study, obesity accounts for 30 million DALYs lost.<sup>22</sup> In the USA, the increasing size of air passengers has necessitated larger seats, increasing emissions per passenger. The intense marketing and ready availability of energy-dense foods in conjunction with low levels of activity has created an environment in which obesity can be seen as a normal biological response rather than a pathological state of an individual.<sup>23</sup>

### Climate change

The effects of climate change on health are discussed elsewhere in this Series by Wilkinson and colleagues<sup>24</sup> and Haines and colleagues.<sup>25</sup>

### Air and noise pollution

Pollution from road transport is a major health hazard. In addition to carbon dioxide, tail-pipe emissions include nitrogen oxide, hydrocarbons, ozone, benzene, lead, and particulate matter, with attention increasingly focused on particles measuring 10 µm or less (PM<sub>10</sub>). The Global Burden of Disease Study estimated that lead exposure, mainly from transport, was responsible for 12·9 million DALYs in 2002.<sup>26</sup> Suspended road-dust and wear of tyres and brake linings are the main sources of particles measuring 2·5–10 µm in many cities. A systematic review of the effects of transport pollution<sup>27</sup> found good evidence for an increase in total mortality, respiratory morbidity, allergic illness and symptoms, cardio-pulmonary mortality, non-allergic respiratory disease, and myocardial infarction and a possible link to lung cancer. Long-term decreases in air pollution are associated with reduced bronchial hyperactivity and respiratory and cardiovascular disease, and consequent gains in life expectancy. Pollution interacts with physical inactivity on cardiovascular disease, and some studies have found diabetes increases susceptibility to air pollution.<sup>28</sup> Rising temperatures from climate change will probably exacerbate the problems of air pollution.<sup>29</sup>

Rapid urbanisation and increasing time spent in congested traffic means that exposure is increasing even where pollution levels are falling. The greatest burden is in the mega-cities of developing countries. With use of 2006 WHO guidelines, urban outdoor air pollution accounts for 750 000 deaths every year, of which 530 000 are in Asia. 16 of the world's 20 most polluted cities are in China, with vehicle emissions increasingly the dominant source of pollution.<sup>5,30</sup> Motorcycles form 75–80% of the traffic in most Asian cities. These vehicles are usually two-stroke engines and burn an oil-petrol mixture, with higher emission levels than four-stroke engines. Within lower-income cities, exposure to particles measuring 10 µm or less is higher for slum residents than for other city dwellers. Slum residents may have to work in the road among dense traffic, and people of lower socioeconomic status suffer more from the same exposure than do people of higher socioeconomic status.<sup>31</sup>

Even in the WHO European region, tens of thousands of deaths per year are attributable to air pollution from transport.<sup>32</sup> Although engines have become more efficient than older types, congestion and increasing numbers of short trips under cold-start conditions have offset this improvement.<sup>33</sup> A UK study found that communities with access to the fewest cars experience the highest levels of air pollution.<sup>34</sup>

Traffic noise is the main source of noise pollution,<sup>35</sup> and has been linked to sleep disturbance and increased

cardiovascular risk.<sup>36</sup> Aviation produces noise and air pollution. Night flights have the greatest effect on local residents and there are high concentrations of nitrogen oxides around airports, although most is from associated car traffic rather than directly from aviation.<sup>33</sup>

Shipping emissions contribute an estimated 10–20% to the overall concentration of particles measuring 10 µm or less for most coastal areas in western Europe.<sup>33</sup> Emissions from international trading ships in the seas around Europe were estimated at 2·6 million tonnes of sulphur oxides and 3·6 million tonnes of nitrogen oxides a year in 2000. The main ports of southern California, USA, are responsible for daily emissions of about 116 tonnes of nitrogen oxides, compared with about 92 tonnes from the 6 million cars in the region.<sup>37</sup>

#### Access and community severance

Achieving high levels of accessibility to shops, markets, employment, education, health services, and social and community networks is essential for health, quality of life, and social inclusion. However, transport policy often focuses on mobility rather than access. The 2006 EU mid-term review of transport strategy states that mobility is the quintessential purpose of transport policy.<sup>38</sup>

Increasing use of cars improves access for those individuals who are newly motorised but reduces access for others through danger and congestion. Danger from high volumes of traffic can make reaching even nearby destinations difficult, which can reduce access to services, employment, and social support networks. These effects are known as community severance, and can affect health in several ways. Particularly hard hit are people who are elderly or disabled, parents or carers pushing prams, and children.<sup>39,40</sup> In the longer term, urban sprawl can reduce social capital and increase social segregation.<sup>41,42</sup> Ecological studies show worse self-reported health in people living in sprawled cities.<sup>43</sup>

Harms are created through too much mobility and too little access. A Dutch study, including freight and passenger transport, found that strategies to achieve substantial reductions in emission would reduce inequalities in the costs and benefits of transport, travel behaviour, and accessibility of economic and social opportunities.<sup>44</sup>

#### Disability and impairment

Transport is a direct cause of impairments, through road-traffic injuries, and an indirect determinant, through physical inactivity. Obesity can be considered an impairment. Moreover, transport affects the quality of life of people with impairments by the creation of enabling or disabling environments. Traffic danger increases the requirements for social participation through the need to judge speeds, see over traffic, and cross roads quickly. The social model of disability views certain environments as creating disabilities in people with impairments. Applying the social model of

disabilities to transport can help us understand how car-dominated transport systems create disabilities beyond those conventionally categorised as having a disability.<sup>45</sup> Training, tricycles, hand cycles, and tandems can increase the take-up of active transport among people with impairments. Small electric scooters with speeds similar to pedestrians or cyclists are a less active but still low energy alternative.

#### Other effects

##### Environment and economy

Investment in motorised road transport is directly and indirectly resource-intensive. This use of resources is closely related to energy use, and raises questions of environmental sustainability beyond climate change. Furthermore, such transport imposes considerable external indirect costs on society. However, transport supports millions of jobs and businesses worldwide and is widely seen as having a special role in economic development.

Transport resource use can be considered as having a health-related opportunity cost. That cost is the lost opportunity to use these resources in ways with a more benign health profile. Although usually standardised in monetary units, the cost can be thought of as specific scarce resources. The opportunity cost can be measured from an individual or societal perspective. Lower-income groups spend a higher proportion of their income on transport than do richer populations. Expenditure on transport is not then available for health care, food, or education.<sup>46</sup> There is little analysis of the health effects of these costs.

From a lifecycle and systems perspective, transport resource includes vehicle production, use, and disposal, together with dependent industries such as construction, oil, steel, rubber, insurance, advertising, and finance.<sup>47,48</sup> Car production uses nearly half the world's annual output of rubber, 25% of its glass, and 15% of its steel.<sup>49</sup> Most motor vehicles are privately owned but road networks are usually led and financed by the state, with high costs. The widening of the M1 motorway in the UK is predicted to cost £5·1 billion, around £21 million a mile. Investment in transport infrastructure mainly benefits those who can afford to take advantage of it. Decisions on transport infrastructure determine the transport options available to individuals and firms, and can act as a substantial subsidy.

The energy use of cars is closely related to their land requirements. These requirements limit land availability for other uses, including agriculture. Estimates suggest that increased transport infrastructure in China will occupy an additional 270 000 km<sup>2</sup> between 2004 and 2020, dispossessing 3·7 million farmers.<sup>5</sup>

Although car and truck use bring substantial economic benefits, the harms impose costs on society not in the main borne by the vehicle user or business. This market failure acts to both encourage further use and discourage



active transport. The economic cost of congestion is over 3% of gross domestic product (GDP) in many cities, with motor-vehicle speeds often slower than those by bike.<sup>50</sup> Road-traffic crashes cost developing countries about 1–2% of GDP each year. The victims of road-traffic crashes are often young adults whose families depend on their earnings. In some cities, air pollution imposes major costs in lost productivity and health-care expenditure. The consequences of physical inactivity are major burdens on health-care resources, with the cost of obesity in the USA estimated at around US\$139 billion per year.<sup>51</sup>

Transfer payments from states and international institutions to automobile manufacturers and fossil-fuel corporations are not a resource use but a transfer that could limit the resources available for health expenditure. Subsidies paid to car manufacturers to keep or attract jobs are common—eg, in January, 2007, the state of Michigan paid Ford \$155 million. According to the Sustainable Energy and Economy Network, the World Bank approved payments, guarantees, and loans worth \$10·7 billion to extraction projects for oil, coal, and gas between 1992 and 2004.<sup>52</sup>

### Environmental sustainability

Ensuring environmental sustainability is the seventh Millennium Development Goal (MDG; webappendix 1). Sustainability has been defined as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. This definition is interpreted in two main ways. Proponents of the weaker version argue that manufactured capital can take the place of natural capital, so it is the combined total capital stock of both that needs to be maintained or enhanced. The stronger interpretation recognises that the functions of natural systems cannot be substituted by manufactured goods and so natural systems themselves need to be maintained or enhanced.

Climate change is occurring in the context of increased anthropogenic stress across a range of natural systems, including stratospheric ozone depletion, loss of biodiversity, spread of invasive species, exhaustion of wild fisheries, and the depletion of freshwater supplies.<sup>53</sup> In addition to its own resource use, transport facilitates the exploitation of other resources. From a climate-change perspective the most important effect is opening up areas to deforestation. Through increasing the demands on our environment's carrying capacity—a capacity not known in advance—energy-intensive transport reduces its human-carrying capacity.

### Oil and energy security

Oil dominates transport energy use; ensuring supply is a driver of international policy. The potential for increasing supply is a hotly debated issue. As conventional oil supplies run down, lower-grade oil supplies with higher cost and greater effect on the environment will become

financially viable. This would mean rising prices and could put transport in conflict with production of plastics, fertilisers and drugs, and other energy demands, hitting those least able to pay. However, the greatest health effect of oil dependency is in countries highly dependent on oil exports. On average these countries have worse health outcomes than other countries at similar levels of economic development,<sup>54</sup> an event known as Dutch disease, and are at greater risk of armed conflict.<sup>55</sup>

### Economic growth and social development

According to the IPCC, reducing transport emissions is difficult because of the role that passenger and freight travel have in social and economic development, and because emission-reduction strategies often challenge the interests of the many transport stakeholders. In webappendix 1 we investigate the role of transport in achieving the MDGs.

Transport allows for a global division of labour and some believe transport investment has a privileged role in economic growth. Although higher per-head GDP is associated with better health in low-income and middle-income countries, there is little correlation in wealthy countries.<sup>56</sup> Air travel is the most energy-intensive form of freight transport, followed by road, then rail and sea. Freight transport is growing faster than economic growth. The falling cost of transport by sea, air, and land combined with just-in-time production systems have encouraged development of global supply chains that see products transported many times between raw materials and final disposal. A 2001 European White Paper describes transport networks as the lifeblood of competitiveness.<sup>57</sup> However, the UK Advisory Committee on Trunk Road Assessment found that transport cost-reduction had only a small contribution to economic growth and productivity, and countries belonging to the Organisation for Economic Cooperation and Development have large variability in their transport-resource use.<sup>58</sup> Moreover, recent research has highlighted how poor health can restrict economic growth.<sup>59</sup>

It is important to consider the developmental effects of transport expenditure separately from the resources transport itself consumes. Choice of transportation system offers different pathways to social development. The achievement of sustainable transport will require decoupling social development and transport energy and resource use.

### Freight and food miles

Although attention on the effect of climate change on agriculture has focused on food miles, the total contribution of bovine emissions of methane is substantially greater. Passenger travel is related to freight because most air freight is carried in the hold of passenger aeroplanes. Popular debate often singles out food freight. However, there is greater natural basis for regional specialisation with food than manufacturing. Moreover,

See Online for webappendix 1

growing vegetables in heated greenhouses can consume more energy than transporting them from warmer countries. Locally grown seasonal vegetables are the most energy efficient. The role of providing an increased range of non-seasonal vegetables and fruit in the reduction in the rates of cardiovascular disease in developed countries is an area for further research and could indicate a health benefit from some food miles. However, attention has to be given to the local effects of export crops on incomes, the nutrient cycle, water supplies, food prices, and land use.

### Transmission of infectious diseases

The movement of populations and livestock shapes the patterns and distribution of infectious diseases.<sup>60,61</sup> Reducing the spread of HIV and malaria is one of the MDGs. One method of transmission that has received attention is the role of truck drivers in HIV transmission (webappendix 1). African on-road settlements have an increased risk of injuries and greater risk of HIV compared with off-road settlements.<sup>62</sup> People on low incomes who live on these corridors have strong incentive to engage in unsafe sexual activity. Climate change is expected to increase the range and seasons for malaria. Aviation also facilitates the rapid spread of infectious diseases, especially for emerging infections.<sup>60</sup>

See Online for webappendices 2 and 3

### Aviation

Apart from its climate forcing, aviation is not associated with as large direct co-harms as road transport. However, airports are usually out of town and can increase road traffic, with its associated harms. Furthermore, claims of the importance of aviation to economic growth and employment are often overstated. There is considerable international variation in flights per head at similar income levels, with the UK well above the European trend line. The effect of investment in aviation is often not compared with the opportunity lost to invest in other areas, which could provide greater employment and similar economic returns.<sup>10</sup> Another argument raised in support of aviation is the economic dependence on tourism in developing countries. However, three-quarters of all UK passenger flights are within Europe,<sup>10</sup> with only a small proportion to developing countries. Although there will be beneficial effects in some areas, these are not likely to be large compared with the unequal effects of climate change.

### Benefits from energy intensive transport

According to the Stern report on the economics of climate change, commissioned by the UK Government, the welfare costs of reducing demand for transport is high.<sup>64</sup> However, travel behaviour might be more amenable to change than most models assume. A systematic review of case studies found that closing roads to car traffic did not cause a corresponding increase on alternative routes.<sup>65</sup> These models often assume that a given destination

provides a set welfare benefit to the traveller and the time to get there is a cost. However, over time, changes in transport infrastructure alter the nature and perceived benefits of destinations. Furthermore, vehicle ownership and distant holidays often function as status symbols, reducing any net benefit.<sup>66</sup>

There are areas in which motor vehicles and aviation provide health benefits. For example, in many settings motor vehicles are central to the operation of health care. However, these modes are able to provide greatest benefit to society if allocated more sparingly and wisely.

There are strong links between the use of fossil fuels for energy and physical inactivity, air pollution, and injuries. These health problems account for a substantial global disease burden and contribute to health inequalities. An integrated assessment of the health and environmental effects of alternative transport is needed.

### Low carbon and healthy transport

There are four main strategies for moving to low-carbon transport while at the same time improving access and equity: avoiding trips; increasing energy efficiency and alternative energy sources; shortening trip distances; and changing travel modes. We look at the effect of these strategies on greenhouse-gas emissions and health in London in webappendices 2 and 3.

### Avoiding vehicle trips

Information and communication technologies—eg, teleconferencing—can replace trips with electronic communication. The rapid development and proliferation of these technologies have transformed societies. Mobile phones offer a low-energy means of communication, and video-conferencing, email, and the internet have a large potential for replacing physical energy-intensive movement. Within health care there have been calls to use information technology to reduce flights by doctors.<sup>67</sup> For freight, internet-based systems can match up spare vehicle capacity and freight needs.<sup>68</sup> However, the effect of such measures is complex and recent research<sup>69</sup> found that information and communication technologies are unlikely to have large effects on their own. Although some trips will be substituted, others will be generated or replaced by fewer longer distance trips. Unless the association between economic growth and energy-intensive mobility is altered, high-energy transport will continue to increase. Other means for reducing vehicle trips include increasing vehicle occupancy and trip chaining, where one round trip replaces several trips.

### Increasing energy efficiency and alternative energy sources

Improved engine design and changes in fuel source are important for reducing emissions. However, although technological solutions are attractive, their development and widespread adoption is problematic, particularly for

aviation. Transport models that examined 60%<sup>70</sup> and 80%<sup>44,71</sup> emission reductions in the UK, Germany, and Holland by 2030 found that technological solutions alone were insufficient.

The average Ford car in the USA is now less fuel-efficient than the Model T manufactured 80 years ago. Improvements in engine design have been more than counteracted by larger heavier vehicles and additional energy-consuming gadgets (eg, air conditioning). Even in the European market, the fall in emissions per vehicle km has not been sufficient to compensate for the increase in vehicle km. Recent plans to introduce tighter emission targets (average emissions from new cars to be 130 g carbon dioxide per km, down from over 160 g carbon dioxide per km) met with stiff opposition from the motor industry. In all markets substantial improvements could be achieved if all motor vehicles had the emissions levels of the lowest, but this would require behavioural change by producers and consumers, because higher-emissions cars remain the most profitable and advertised.

Alternative energy sources offer another route to lower emissions. In this context it is essential to realise that the higher are the absolute energy demands, the lower is the proportion that can be provided by a given amount of low-carbon energy. Therefore, providing sufficient renewable energy to power public transport is more feasible than for private motor vehicles. Although biofuels can supply some transport energy, the process is inherently not efficient enough to substitute for all transport fossil-fuel use at current levels. The production of soya and palm oil has increased greenhouse-gas emissions through deforestation. A recent UN energy report argued that bioenergy offers greater emission reductions used for generating combined heat and power, rather than fuelling transport.<sup>72</sup> Other effects on health depend on how alternative energy sources affect air pollution, food production and prices, and farm income in poor areas. Electricity or hydrogen generated by nuclear power comes with long-term waste disposal problems and a shorter-term low probability of accident risk. Development of renewable sources of electricity is essential, but producing large amounts of hydrogen from renewable energy is at least 30 years in the future. A review of funding of buses fuelled by hydrogen in developing cities by the UN Development Programme found the cost to be about \$2.6 million per bus.<sup>73</sup> Furthermore, if the hydrogen is derived from coal-based electricity, greenhouse-gas emissions will be higher than if a standard diesel vehicle was used.

Electric and hybrid vehicles offer the greatest opportunity for short-term technological solutions. However, even if tail-pipe emissions are avoided, the large energy and resource use of cars during their lifecycle make the development of a truly environmentally sustainable car an illusion.<sup>47</sup>

Efficiency gains from aviation are not expected to exceed around 1.2% per year,<sup>10</sup> far below the predicted

growth in flights. Radical changes to airframe design are not likely to be available for decades and could benefit long haul flights only.<sup>75</sup> Biofuels are more problematic for aviation than for cars. Hydrogen is not feasible in the medium term, and would produce more water vapour, which at altitude is a greenhouse gas.

### Shortening trip distances and changing travel modes

Urban form and infrastructure is key to transport sustainability.<sup>41</sup> Higher-density land-use is inherently more energy-efficient because distances are shorter. Combined with developments in public transport, higher-density enables a more frequent and higher-occupancy public transport with lower emissions per passenger. Mixed-use developments, better housing location and building design, and support for local services can reduce travel distances to employment, education, health services, and shops. These developments in turn encourage a shift in the mode of transport, and improve the safety and attractiveness of cities. Measures to encourage active and public transport should be combined with strategies to reclaim so-called released space from the car and to restrict car travel, otherwise car travel speeds will rise, increasing its attractiveness (rebound effects).<sup>68</sup>

There is substantial variation in active transport between high-income countries (eg, over four times greater in Europe than in the USA).<sup>63</sup> In some European cities, cycling accounts for about a third of trips (eg, 32% in Munster, 37% in Delft) compared with under 2% in London. High levels of active transport are achievable by older people who have the potential for large absolute gains in health: in Holland and Germany, over 50% of trips by those aged over 75 years are by foot or bike.<sup>63</sup>

In low-income and middle-income cities, most journeys are by foot, public transport, or in some cases bicycle. Here, the non-car-user should be able to win political backing for policies that support active transport. However, the needs of the majority routinely fall far behind those of car users<sup>73,76</sup> and infrastructure for pedestrians is often of a low standard. Pavements, where they exist, are often obstructed,<sup>77</sup> and restrictive measures imposed on pedestrians restrict choice of road crossing.<sup>7,78</sup>

When road space is shared between modes of transport, sharing tends to be on motor-vehicles' terms. Cycling is thus seen as too dangerous, and buses are preferred where available and affordable. The transport needs of slum dwellers receive little attention. Low-income populations often live at the edge of the cities and have the furthest distance to travel, often by foot, with corresponding exposure to the harms of motor vehicles. Some end up living on the street during the week because the journey is too long or expensive.<sup>46</sup> Cycling in many large African cities has collapsed. In Nairobi, the share of trips by bike fell from 20% in the 1970s to 0.5% in 2004.<sup>78</sup> In many east Asian cities, although under threat, cycling retains a high modal share and the opportunity exists for this to be



retained and expanded. Unfortunately, governments and international institutions, even when willing to support public-transport investment, see cycling as an intermediate technology and characteristic of underdevelopment.

One city that has moved in the right direction is Bogotá, Colombia, which has seen increases in cycling, improvements in air quality, accessibility, and quality of life.<sup>73</sup> In Bogotá, Bus Rapid Transit (BRT) provides a frequent and fast service on a separate network from other motor vehicles. This service was introduced in conjunction with policies to restrict car use, including weekly car-free days and major parking restrictions, and improved active-transport infrastructure. BRT is more affordable (around \$1–\$15 million per km) compared with a \$50–\$200 million per km system for rail or underground travel.

The same principles can be applied to freight transport: transferring to less energy-intensive modes, human-powered vehicles (especially in the urban environment), and rail or shipping, rather than truck or plane. Developing policies to reduce the high proportion of deaths caused by trucks is essential if active transport is to be supported.<sup>74</sup> Sustainable freight would require the distance travelled by a commodity through its lifecycle from raw materials to disposal to be reduced through relocating production closer to markets, redesigning supply networks, and more local purchasing. The movement of finished motor-vehicles, their components, oil, and other raw materials constitutes a substantial proportion of total freight volume, so a reduction in use of motor vehicles would have knock-on benefits.

For aviation, the greatest potential for replacing short flights is by rail. However, faster trains have greater energy requirements. For longer distance or trans-ocean flights, the potential for direct substitution is much less. Shipping freight is considerably more efficient than by air, but for passenger travel, the need for more space and facilities due to the longer travel time mitigate much of the greater efficiency. However, aviation encourages longer journeys than would be undertaken by any other mode. Important decisions on aviation capacity are currently being made. A predict-and-provide approach would lock-in dependence on aviation, making future reductions more difficult.

### Active transport

Active transport offers the greatest potential to improve health and lower transport-energy use. These modes increase physical activity, are non-polluting, pose little danger to others, and are socially inclusive. In most settings the greater scope is to increase cycling, which is the lesser used mode of transport. Some cities—eg, Berlin, Copenhagen, and Bogotá—have achieved substantial increases in cycling. Already substantially more bikes than cars are produced each year and global ownership is far higher. The bicycle is the most energy-efficient means of transport and offers access to an area more than ten times greater than walking. Cycling and walking are complementary. Some people are able to walk or cycle but not both.

Cross-sectional studies have found environmental attributes of streets and communities (eg, connectivity) and accessibility of destinations to be correlated with increased active transport.<sup>79,80</sup> However, there has been little good prospective work. The few controlled interventions have tested only small-scale interventions and found small effects.<sup>81</sup> The best option for rapidly improving the evidence base is applying prospective study methods to the natural experiments offered by development and changes in transport systems. The table shows policies to promote active transport in the urban setting.

These strategies offer the opportunity to move towards a low-carbon healthier transport-system. A combination of approaches is necessary to ensure that gains from information and communications technology, energy efficiency, and low-carbon fuels are not lost due to substitution, larger vehicles, and longer distances. The key to urban sustainable transport is local neighbourhoods, well-served and easy to navigate by active transport, supplemented by high-quality public transport powered by renewable energy for longer journeys. Physical activity would be increased while at the same time reducing local air pollution, greenhouse-gas emissions, and community severance. Road danger is reduced through lower traffic volumes and better street design. The street becomes more inclusive, and a central hub of the community for play and informal socialisation. Such a future would provide inclusive levels of accessibility without cars.<sup>47</sup>

	Walking	Cycling
Reallocating space and time	<p>"Woonerfs" or home zones: Space shared by pedestrians, bicyclists, and low-speed motor vehicles, without curbs or pavements. Vehicles are slowed &lt;16 km/h by road narrowing and obstacles, such as trees</p> <p>Less car parking</p> <p>Lower speed limits</p> <p>Longer pedestrian crossing times</p> <p>Improved connectivity and permeability for pedestrians and cyclists including:</p> <p>Wider pavements</p> <p>Pedestrianised areas</p> <p>Road crossings at most convenient places for pedestrians</p> <p>Grid layouts not cul-de-sacs</p>	<p>Less car parking</p> <p>Lower speed limits</p> <p>Priority at junctions</p> <p>Opening up road closures to cycle traffic</p> <p>Closing roads to through motor vehicles</p> <p>Removing one-way systems or allowing contraflow cycling</p> <p>Grid layouts not cul-de-sacs</p>
Making use easier and more pleasant	<p>Human scale, mixed-use urban villages, with unique identities. Improved local services, neighbourhood events and activities</p> <p>Accessible public transport for pedestrians and cyclists</p> <p>High-quality pavements, pedestrian orientated lighting, benches, and public art</p>	<p>Secure, convenient parking facilities.</p> <p>Changing rooms and showers at work.</p> <p>Ramps</p>
Legal priority	Requiring motorists to anticipate the variability of walking and cycling practices	
Financial	Carbon permits, fuel and road taxation, parking charges. Payments/discounts for cycling to destinations	

\* Active transport principally refers to walking and cycling, but also includes non-motorised wheel chairs, scooters, skateboards, and roller skates or blades.

**Table: Policies prioritising active transport\***

## Conclusions

The health effects of transport are intimately related to transportation energy-use. Car and truck travel have co-harms, whereas active transport has co-benefits. Achieving the MDGs requires investment in transportation that meets the needs of poor people (webappendix 1). Levels of car use and air travel currently enjoyed by high-income groups are not sustainable or generalisable. These modes do not provide equity in access and are socially divisive. The growth in these modes will adversely affect the welfare of future generations.

Rapid reductions in emissions require changes in behaviour, technology, and land use (see webappendices 2 and 3 for a case study). There exists the potential of a modal shift from oil-based car transport to food-based active transport, to yield important health benefits for car users and wider society, through reductions in air pollution, physical inactivity, and opportunity costs. Future research should quantify these effects under alternative scenarios. The greatest potential for health gain is by improving the walking environment and supporting the most energy efficient form of transport—the bicycle. The necessary changes are achievable and affordable and essential for sustainable development across settings. Levels of cycling can be used as a measure of progress towards a healthier sustainable future in both the developed and the developing world. The main obstacles to progress are not technological but political, in particular the financial interests of stakeholders.

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