Ministry for the Environment
Manatū Mō Te Taiao

The co-benefits of emissions reduction

An analysis

New Zealand Government

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Executive summary

This report summarises the available evidence on the co-benefits of policies to reduce greenhouse gas emissions. The transition to a low-emissions economy will bring many costs and benefits, which are often discussed and included in economic analyses and summarised in marginal abatement cost curves (MACCs). However, the transition will inevitably have knock-on effects, known as externalities or spillovers. These spillovers are generally positive, hence we refer to them as co-benefits. However, where negative spillovers could occur, they are noted in this report.

This report does not look at the innovation benefits afforded by a low-emissions economy or the distributional impacts on the most vulnerable.

Understanding co-benefits can help justify emissions reductions activities and could also alter the mix of emissions reductions policies pursued in the transition to a low-emissions economy. Careful policy design should aim to maximise the co-benefits and minimise the potential costs of a transition to a low-emissions economy. A key example is transport; in New Zealand electric vehicles are seen as the key low-cost way of reducing emissions. Co-benefits from active transport (eg, walking, cycling) and public transport are far higher, and they could be high enough to warrant being part of the policy mix.

Co-benefits can be difficult to quantify and compare. The various results discussed in this report are created using various methodologies and should preferably be used as a general guide to assess the scale of co-benefits to prioritise further work. A more reliable approach, however, is comparing the co-benefits with the direct emissions reductions benefits of different policy actions. This allows policy-makers to identify the areas where including the co-benefits could make the largest difference to the benefit-cost ratio.

Based on this approach, the policy objective with the largest co-benefits relative to emissions reductions are:

- energy efficiency
- freight to rail
- active transport
- public transport
- forestry.

The first four of these are strongly linked to demand management.

The largest source of co-benefits appears to be in the health sector, with key factors including the reduced spread of non-communicable diseases, fewer accidents and improved air quality. International literature has recognised the health impacts of improved air quality as a major co-benefit (Metz et al, 2007). Air quality is relatively good in New Zealand, so while it is still relevant in the New Zealand context (particularly in eliminating coal use), the dominant health benefits are more likely to come from increasing exercise, reducing accidents and improving the quality of housing stock.

Reduced congestion is also a key co-benefit of active and public transport. Active and public transport is more efficient at moving greater numbers of people given limited space on the transport network. While electric vehicles are considered to be the key answer to reduced transport emissions, they will not reduce congestion or the number of accidents, nor will they encourage people to get exercise as part of their daily commute.

The environmental co-benefits of reducing agricultural emissions and changing land use to forestry are also worth noting, particularly improvements in water quality. Many of the possible ways to reduce agricultural emissions are still in development, and it is likely that many of the innovations to reduce methane emissions will have no co-benefits. However, existing approaches such as improved farm practices and land use changes, including reduced livestock numbers, could reduce both nutrient loss and greenhouse gas emissions by a meaningful amount without impacting on profitability. Examples of improved farm practices include the use of alternate feeds or lower emitting animals.

We can expect land use change to forestry to bring larger co-benefits, particularly in terms of water quality (reduced nutrient leaching and sediment) and improved biodiversity. On marginal land, land use change to forestry may bring overall benefits.

Introduction and scope

Climate change mitigation efforts in New Zealand have traditionally been analysed on the basis of direct financial costs and benefits. This ignores the many externalities or spillover costs and benefits that climate change mitigation tends to have.

According to IPCC (2014):

> Climate policy intersects with other societal goals creating the possibility of co-benefits or adverse side-effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action.

Bain (2016) shows that co-benefits can help motivate action, particularly in communities that did not see climate change action as important. This can be particularly successful if the actions can be linked to economic development or the creation of a more caring community.

Metz et al (2007) points out policies are more likely to be implemented if they have co-benefits. This is because the benefits of emissions reductions are largely a public good that are shared by the entire world rather than those making the emissions reductions. By contrast, the co-benefits of emissions reductions are often more tangible and local, so more appreciated by the local population.

Metz et al (2007) also points out the co-benefits are often not considered in policy analysis and, if fully integrated, can help improve the benefit-cost ratio of many emissions reduction policies. In some cases, the co-benefits can be as large as, or even larger than, the benefits of emissions reductions themselves.

This report summarises the available evidence on the co-benefits of emissions reductions policies. Recognising co-benefits can help take a more holistic view of policy actions. They help link emissions reductions to other policy agendas, highlighting where there might be complementary outcomes (or clashes). Co-benefits can highlight policies that may not be important for the sole purpose of reducing emissions but rather for their holistic impact on well-being.

The focus of this report will be on the evidence of any co-benefits related to emissions reduction policies. While we do not yet know the policy mix that the New Zealand Government will use, there has been extensive work on pathways to a low-emissions economy that implies a series of policy objectives. The report looks at the main policy objectives set out in the Vivid Economics report on the transition to a net zero emissions economy (Kazaglis et al, 2017), grouped by the sources of greenhouse gases.

For each policy objective, the report will describe:

- the intermediate pathways (ie, how the actions to reduce emissions will lead to other impacts)
- the actual co-benefits
- the scale of those co-benefits, both in absolute terms and relative to the emissions reductions
- the strength of evidence of co-benefits.

The scale of co-benefits is often difficult to compare across different policies, as the studies drawn on for this paper deployed a variety of valuation methodologies. This report mentions some of these methodological problems, such as having a consistent basis for quantifying deaths from air quality compared with exercise. Others are more fundamental, such as using the Ministry of Transport's 'social cost per life saved' to monetise health outcomes. Some deaths (such as accidents) can happen anywhere in a lifetime, while others (chronic disease) tend to shorten life by a few years on average. Not all deaths are equal in terms of disability adjusted life years (DALY[1]) lost; ideally there would be a measure to value this and allow for more accurate estimates of health costs and benefits.

To reduce these methodological issues, this report makes an effort to compare the scale of co-benefits *relative* to the emissions reductions. This gives us an idea of where to prioritise the inclusion of co-benefits in the policy analysis for certain options. While the analysis compares the co-benefits relative to emissions reductions, we recognise that different sectors contribute different levels of emissions.

There will also be co-benefits from reducing emissions in terms of limiting the damage of climate change and ocean acidification. However, New Zealand's emissions are small in the global context, so the direct co-benefits from policies to reduce our own emissions are small. Limiting the damage of climate change requires not only reducing our own emissions, but also ensuring that the rest of the world reduces theirs.

The direct costs and benefits of policies to reduce emissions will be picked up by the economic modelling for those policy objectives. The economic co-benefits of placing a price on emissions will also be covered in a separate report on innovation and competitiveness.

The remaining externalities of emissions reductions are generally positive. There are, of course, costs of emissions reductions policies, but most of these are picked up in the financial and economic modelling on the costs of a transition to a low-emissions economy. Occasionally there are spillover costs from policies to reduce emissions that should also be considered during the policy design process. These are mentioned where relevant in this report. With good policy design, it should be possible to maximise the co-benefits of emissions reductions policies and minimise any spillover costs.

It is worth noting this report is written from the current paradigm of emissions accounting. For example, the analysis on emissions from food production is taken from the perspective of the producer (which currently bears the burden of emissions created) rather than the consumer. Reducing emissions embedded in the food eaten by consumers is not currently seen as a policy objective, other than as a side effect of reducing the emissions in New Zealand's food production.

[1] DALY is a metric used to try and measure the overall cost of poor health, expressed as the number of years lost due to illness, disability or premature death.

Cross cutting

Stronger emissions pricing

Emissions pricing is already an established part of the policy mix. As the main policy tool for reducing emissions it does not require intensive analysis. A strong, long-term emissions price signal could not only contribute to the other policy objectives discussed later in this report, but could also raise revenue to reduce the distortionary impacts of other forms of taxation.

Intermediate pathways

The long-term goal of emissions pricing is reducing emissions to zero, at which point it will cease to be an effective revenue raiser. However, stronger emissions pricing in the interim has the potential to raise substantial revenue. This revenue could be used to reduce other forms of taxation while reducing its distortionary impacts. The degree of benefit from such a switch depends on the level of distortion caused by taxation (Scrimgeour & Piddington, 2002).

New Zealand's tax system is seen as relatively non-distortionary, especially compared to overseas jurisdictions. From an equity perspective, the Goods and Services Tax (GST), in particular, is a regressive tax, meaning people on low incomes pay more tax as a proportion of their income.

From an environmental perspective, income tax and GST may potentially create an artificial incentive for employers to reduce the quantity of labour used in the production process. This favours the current economic model, the so-called 'linear economy' with a 'take, make and dispose' approach to using natural resources. In contrast, the circular economy attempts to 'reduce, reuse and recycle' resources. Transitioning to a circular economy will require careful use of natural resources and greater input of labour to repair, recover and reuse resources. This shift would be helped by reduced taxation on labour and increased taxation on natural resource use (The Ex'Tax Project et al, 2016). As it is effectively a tax on fossil fuels, stronger emissions pricing complements this approach.

Co-benefits

If a stronger emissions price were made tax-neutral, theoretically, it could allow for reductions in income tax and/or GST. This would ensure that the costs of an emissions price on economic activity in some parts of the economy were offset by benefits elsewhere. Such a change could also encourage employment, which is less of an issue in a time of low unemployment but may become important in an increasingly automated future. This change could reduce the tax distortion against labour-intensive industries, which is a barrier to the development of a circular economy.

The Government's Tax Working Group is currently considering what role the taxation system can play in delivering positive environmental outcomes, especially over the longer term.

Scale of co-benefits

The exact amount of revenue that could be gathered depends on the policy settings of the Emissions Trading Scheme, including overseas trade, price caps, auctioning credits, free allocation and whether agriculture is included in the scheme.

The revenue from environmental taxation in New Zealand is relatively low at 1.5 per cent of gross domestic product (GDP) (Organisation for Economic Co-operation and

Development (OECD), 2016) currently. Several OECD countries such as Denmark, Italy and the Netherlands collect double (or more) environmental taxation as a percentage of national income, suggesting there is some scope for an increase in environmental taxes in New Zealand.

Strength of evidence

New Zealand's tax system is not hugely distortionary, and any such changes would need to be large to have a real impact on the shift to a circular economy. Real world evidence to support large changes is weak, because few countries have moved to environmental taxation as a major source of revenue. However, most other OECD countries have higher levels of environmental taxation compared to New Zealand, without obvious signs of any resulting economic problems. The concept has a strong grounding in economic theory, provided it is revenue-neutral, and therefore seems likely to have a positive though small impact.

Energy

Energy efficiency

Improved efficiency of energy use is one of the most obvious ways to reduce emissions, often yielding direct economic benefits (Kazaglis et al, 2017). However, this strategy also offers co-benefits, mainly in terms of health but also in reduced electricity infrastructure investment.

Intermediate pathways

Exposure to extreme heat, cold, damp and mould are risk factors in many non-communicable diseases, such as respiratory problems and cardiovascular disease (World Health Organization, 2012). Children that suffer respiratory problems are more likely to continue to suffer these problems throughout their lives (Gillespie-Bennett et al, 2013).

Appropriate insulation and ventilation of homes is a major factor in reducing cold, and houses that are cold are also more likely to be damp (Gillespie-Bennett et al, 2013). Insulation can improve temperatures and reduce dampness, particularly reducing exposure to extremely low temperatures in winter. As a result of insulation, self-reports of wheezing, taking days off school or work and visits to the GP or hospital were reduced (Howden-Chapman et al, 2007).

Business energy efficiency improvements bring obvious and immediate benefits to profit, which are captured by standard economic analysis. However, there is evidence of potential knock-on benefits as well, with businesses that have made energy efficiency improvements becoming more likely to increase employment in the future (Metz et al, 2007).

Energy efficiency, if applied at times of peak demand, can also reduce pressure on the electricity distribution network, reducing the need for additional investment (this concept is discussed in detail under the demand management section below).

Co-benefits

The potential health co-benefits of improved home insulation are significant. New Zealand has one of the highest rates of asthma in the world, with one in six adults affected, at a total estimated cost of $800 million per annum. This is likely to be linked to our poor standard of housing; one-third of New Zealand homes remain uninsulated (Holt & Beasley, 2001; Gillespie et al, 2013). The *2015 House Condition Survey* showed 830,000 houses in New Zealand have sub-optimal roof insulation and/or sub-floor insulation (White & Jones, 2017).

Those living in the poorest quality housing could see their respiratory problems fall by one-third if their housing improved (Gillespie-Bennett et al, 2013). There are also an estimated 1600 additional deaths each winter that may be attributed to the impact of cold (Davie et al, 2007).

Scale of co-benefits

The benefit-cost ratio of insulating previously uninsulated houses is estimated at 4:1 generally and even higher for at-risk groups (children and the elderly). The bulk of this benefit comes from the health gains, rather than emissions reductions, as most people choose to maintain (or even increase) energy use and have a warmer house (Grimes et al, 2012). On average across all newly insulated homes, the relative health co-benefits are far higher than the emissions reductions benefits.

Concept Consulting (2017) has estimated potential present value benefits of $480 million from a $140 million investment in energy efficiency. Of those benefits, $60 million are emissions reductions, $100 million comes from lower spending on generating power and $280 million comes from lower investment on electricity distribution and generation infrastructure. This is predicated on the energy efficiencies being realised during peak times, thereby reducing the pressure on the electricity distribution infrastructure (see the demand management section below).

Strength of evidence

The evidence of health co-benefits from improved insulation is strong, as is the potential for infrastructure savings, although this is predicated on the efficiencies being realised at peak time.

Renewable electricity

This section looks at the co-benefits from actions to increase the proportion of electricity generated by renewable sources. There may be some health and possibly employment co-benefits from this.

Intermediate pathways

A possible co-benefit of renewable electricity generation displacing fossil fuel electricity generation is reduced air pollution. However, this depends on the type of renewable generation and the type of fossil fuel it is displacing. There are air quality impacts from geothermal and biomass-based electricity generation (even though they are renewable), so we cannot make any definitive statements here.

For employment, the labour intensity of renewable energy jobs in Poland has been estimated at 10 times higher than that of traditional coal power (Metz et al, 2007). This calculation is heavily based on local economic characteristics and cannot be readily generalised to the New Zealand context without further work.

Co-benefits

Air pollution from human activity is estimated to cause around 1000 premature deaths per year. For a greater number of people the more noticeable impact is days when their activity is restricted due to air pollution; the estimate is 1.35 million restricted activity days lost per annum (Ministry for the Environment and Statistics New Zealand, 2014).

This estimate needs to be treated with caution in the context of this paper. The methodology is different from that used to attribute deaths to lack of insulation, insufficient exercise or poor diet, as discussed elsewhere in this report. These other estimates are created as part of the Global Burden of Disease study (Ministry of Health, 2016). Using a like-for-like methodology reduces the estimate for air pollution deaths from 1000 to 570, which is 1.75 per cent of all premature deaths and 0.81 per cent of all disability adjusted life years lost.

Because of the range of gases and conditions involved, it is difficult to know how much different pollution sources contribute to those health problems; however in New Zealand, home heating is generally seen as the main driver, followed by motor vehicles and then industrial sources (Kuschel et al, 2012). The spatial impacts of this pollution vary, with home heating being a major driver in the south of the country and industrial pollution depending on the location of electricity generation. Shifting to renewable electricity would entirely eliminate electricity generation as a source of air pollution.

Scale of co-benefits

The total cost of deaths related to air pollution is estimated at $4.28 billion per year (Kuschel et al, 2012). For methodological reasons stated above, this is likely to be an overestimate; it does not include the costs of hospitalisation or restricted activity. A complete shift to heating with renewable electricity promises to eradicate the contribution of electricity generation to air pollution completely, with resulting health benefits. However, electricity generation is only likely to be the key driver of negative health impacts in very limited number of areas (eg, Huntly). Overall, the co-benefits are likely to be similar to the benefits of emissions reductions.

Strength of evidence

The strength of evidence is moderate. The quality of data on air pollution and the resulting health impacts is reasonable, but it is difficult to attribute this to different sources. Employment benefits are speculative.

Electric vehicles

The shift to electric vehicles[2] will have a large impact on reducing emissions, but there will also be co-benefits for health of a comparable scale. It is important to note, however, that the co-benefits for a shift to active or public transport are far higher.

Intermediate pathways

Air pollution causes a range of problems including respiratory and cardiovascular disease, as well as some forms of cancer (World Health Organization, 2012). The main co-benefit of electric vehicles is reducing the air pollution that results from the burning of fossil fuels. Burning petrol and diesel cause motor vehicles to be the largest source of nitrogen oxides and carbon monoxide in the air. Motor vehicles also emit some particulates, although home heating is a far greater source of these.

In major urban centres, levels of nitrogen dioxide and benzene can exceed international guidelines (Ministry for the Environment, 2015). In Auckland, the risk from motor vehicle fumes significantly outweighs the air pollution risks caused by home heating (Kuschel et al, 2012). Air pollution caused by motor vehicles is falling over time, despite an increase in vehicle kilometres travelled, thanks to improved emissions standards and fuel quality (Ministry for the Environment, 2015).

Diesel vehicles have lower carbon emissions but higher emissions of particulates and nitrogen oxides (Parliamentary Commissioner for the Environment, 2015). Therefore, encouraging a fuel switch to diesel vehicles could have a questionable overall impact on well-being. If larger diesel vehicles are slower to switch to electricity as expected, then a larger portion of the air quality benefits are also likely to be delayed.

Electric vehicles also have lower levels of noise than the standard internal combustion engine. Noise pollution is the most frequent complaint to local councils under the Resource

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[2] In addition to electric vehicles, we may see the uptake of other low emission technologies such as advanced biofuels. Advanced biofuels will have all the same adverse air quality impacts as existing fossil derived fuels.

Management Act. Noise pollution near roads has been shown to disturb sleep, affecting cognitive function and increasing the risk of cardiovascular disease.

There may also be benefits from increased fuel security from a shift to electric vehicles. Currently, New Zealand imports most of its transport fuel, but the electricity to power electric vehicles would be provided locally. This could potentially insulate the New Zealand economy from the costs of a spike in oil prices. However, calculating the benefits of any energy security requires a complex and speculative calculation, as the future costs of fossil fuels are unknown and New Zealand would still be reliant on foreign purchased technology for electric vehicles, batteries and renewable energy generation. It is also unclear how expensive it would be to have 100 per cent renewable electricity generation and what the risk would be to security of supply. The cost of generating electricity for charging electric vehicles depends strongly on when that charging takes place (which is discussed further under Demand Management).

Co-benefits

Using the methodology discussed in the renewable electricity section, it is estimated that air pollution from human activity causes 570 premature deaths per year. For a greater number of people, the more noticeable impact is days when their activity is restricted due to air pollution; the estimate is 1.35 million restricted activity days lost per annum (Ministry for the Environment and Statistics New Zealand, 2014).

Because of the range of gases and conditions involved, it is difficult to know how much different pollution sources contribute to those deaths; in New Zealand, motor vehicles are generally seen as secondary to home heating as a cause (Kuschel et al, 2012). Shifting to electric vehicles would almost entirely eliminate motor vehicles as a source of air pollution (apart from dust and tyre particles).

Noise pollution is estimated to cost the European Union about €40 billion each year, roughly 0.4 per cent of its GDP (den Boer & Schroten, 2007). No estimates are available for New Zealand.

Scale of co-benefits

The total cost of deaths related to air pollution is estimated at $4.28 billion per year (Kuschel et al, 2012). For methodological reasons stated in the renewable electricity section above, this is likely to be an overestimate, although it does not include the costs of hospitalisation or restricted activity. Depending on location and time of year, the contribution of transport to this total is likely to be secondary to home heating. In northern cities like Auckland, vehicles could be the major driver of air pollution, particularly near busy traffic sites. A complete shift to electric vehicles promises to eradicate the contribution of motor vehicles to air pollution almost completely. However, switching diesel-powered freight to electricity is likely to take longer to transition, so a large proportion of those benefits could be delayed until that time.

Despite a relatively small number of lives saved that can be attributed to reducing vehicle emissions, the value placed on human life means that the air pollution benefits of shifting to electric vehicles are likely to be less than or similar to the value of emissions reductions at the current emissions price (approximately $300 million per annum at the current emissions price).

Electric vehicles will also reduce the dependency of New Zealand's economy on imported fossil fuels. As noted above, any resulting benefits are speculative, although they are more likely to appear in a world facing disruption caused by climate change. Based on overseas estimates, the benefits of reducing dependency on imported fossil fuels amount to around US$5-12 per tonne of carbon dioxide (CO_2) reduced (Global Commission on the Economy and Climate, 2015). This co-benefit is, therefore, likely to be small relative to the emissions reductions benefits.

Strength of evidence

The strength of evidence is moderate. The quality of air pollution data and the resulting health impacts are reasonable, but it is difficult to attribute these to different sources. Fuel security, noise and water pollution benefits are more speculative.

Freight to rail

Switching road freight to rail (or other modes such as shipping) may bring additional benefits to simply electrifying the freight fleet.

Intermediate pathways

Putting more freight onto the rail network would reduce the amount of trucks on the road, leaving greater space for other road users. This would be particularly valuable in congested areas of the network; for example, during peak travel times in cities. Road users currently do not pay for the congestion costs they create, and freight carriers are no exception.

Freight users pay for the average costs of their wear and tear on roads through road user charges (RUCs). However, this does not account for the *marginal* wear and tear generated, as increase in road freight compounds the problem.

Carrying freight by road also increase the risk and cost of accidents. Trucks are generally safer than passenger vehicles, but accidents involving trucks have far higher rates of death and serious injury (EY, 2016). The costs of accidents are not fully internalised into ACC levies, particularly in the case of death.

Co-benefits

Traffic congestion costs households and businesses in Auckland an estimated $0.9-$1.3 billion every year in lost time and economic activity (New Zealand Institute of Economic Research, 2017).

Around 23 per cent of the $4 billion spent annually on our roads goes on maintenance. Road freight is likely to cause the bulk of wear and tear on the main routes they traverse.

The road toll in 2017 was 380 deaths and injury numbers have ranged from 11,000 to 13,000 per year over the past few years. The social cost per life saved is $4.14 million (Ministry of Transport, 2017).

Scale of co-benefits

The degree to which it is possible to switch from road freight to rail in New Zealand is not fully known. However, Ernst and Young (2016) gives an idea of the relative scale of co-benefits based on the current levels of freight use in the rail network.

The largest benefit from the current rail freight service comes in reduced congestion on the roads, valued at between $200-208 million per year. Next comes maintenance benefits of $77-80 million, followed by safety benefits of $56-61 million. The total emissions reduction benefit is around $6 million, less than two per cent of the total benefit from the current rail network.

That number could increase slightly with increased electrification, but these other co-benefits are likely to continue to dominate.

Strength of evidence

The strength of evidence is moderate. It is clear the co-benefits are large compared to the emissions reductions benefits, although the scope for increased transport of freight by rail is unclear.

Public transport

While increasing the use of electric vehicles is often the focus of emissions reductions in New Zealand's transport sector, the potential for co-benefits are far higher through increasing use of both public and active transport.

Intermediate pathways

Increased use of public transport means fewer vehicle kilometres travelled in private cars. Switching modes from private cars to public transport reduces congestion and saves considerable space in cities. Public transport is able to hold 27 times more passengers per square metre of road occupied, including parking (Litman, 2015). This will also reduce costs associated with building infrastructure and create benefits in time saved.

Public transport is safer than a private vehicle. The risk of being killed or injured as a passenger in a bus is seven times lower than for driving a car and four times lower for being a passenger in a car per kilometre travelled (Ministry of Transport, 2015). Public transport uses f fuel more efficiently than private transport, which reduces air pollution.

There is evidence overseas that increased use of public transport over private vehicles increases exercise, resulting in health benefits (Martin et al, 2015). However, there is no evidence of this in the New Zealand case from the limited surveys conducted, so this potential benefit has not been included in this analysis (Shaw et al, 2017).

Co-benefits

The major co-benefits of a switch to public transport are reduced congestion, better safety and improved air quality respectively.

Traffic congestion costs households and businesses in Auckland an estimated $0.9-$1.3 billion every year in lost time and economic activity (NZIER, 2017).

The road toll in 2017 was 380 deaths and injury numbers have ranged from 11,000 to 13,000 per year over the past few years. The social cost per life saved is $4.14 million (Ministry of Transport, 2017).

Around 570 premature deaths occur every year as a result of air pollution (Ministry of Health, 2016; Ministry for the Environment, 2015). Vehicle emissions are likely to be the second largest cause of this, although that will depend on location; in Auckland vehicle emissions are likely to be the key driver of air pollution deaths (Kuschel et al, 2012).

Almost all of these negative impacts could be averted by a large scale switch to public transport. Such a complete shift in modes is unlikely, but even bringing other New Zealand cities up to the levels of public and active transport seen in Wellington (6.2% of trips) would create considerable benefits for congestion and health (Shaw et al, 2018).

Scale of co-benefits

The scope for increased use of public transport as a result of cost effective investment in New Zealand is not known. However, Ernst and Young (2016) estimates the total value of the existing passenger rail network in Auckland and Wellington is between $1.132-1.183 billion, of which, reduced congestion generates almost all the benefits.

Safety benefits from a mode switch are likely to be small compared to the congestion impacts. The safety benefits of the Auckland and Wellington rail networks were less than one per cent of the total benefits. The benefits of emissions reductions were also less than one per cent of the total. This suggests that, for increased use of public transport, the congestion co-benefits will outweigh climate benefits by an order of magnitude. The Ernst and Young (2016) study did not look at air pollution benefits, but these are likely to accompany climate benefits and be a similar order of magnitude.

Strength of evidence

The strength of evidence is moderate. The congestion benefits of public transport are large, but the potential for cost-effective investments to increase public transport use are not known.

Active transport

While increasing the use of electric vehicles is often the focus of emissions reductions in New Zealand's transport sector, the potential for co-benefits are far higher in options that would increase use of both public and active transport.

Intermediate pathways

Increased use of active transport means fewer vehicle kilometres travelled in private cars. Switching modes from private cars to active transport saves considerable space in cities. Cycling takes up $1/18^{th}$ of the space of cars, including roads and parking (Litman, 2015). As a result, the increased use of active transport reduces congestion, which in turn reduces costs associated with building infrastructure and creates benefits in time saved.

Increase in active transport (eg, walking and cycling) will lead to increase in l exercise overall. Active transport is unlikely to be offset by increased calorie intake or reductions in other forms of exercise. As a result, those people who use active transport are 76 per cent more likely to meet the minimum recommended guidelines for exercise (Shaw et al, 2017). Insufficient exercise is associated with higher levels of type 2 diabetes, heart disease, some forms of cancer and mental health problems (WHO, 2012). Bringing London up to similar levels of cycling as some other European cities could reduce heart attacks and strokes by 10 to 20 per cent, breast cancer by 12 to13 per cent, dementia by eight per cent and depression by five per cent (Watts, 2010).

One confounding factor is cycling is a riskier form of transport per km travelled. A shift to cycling could lead to greater number of transport accidents, but the Government has signalled increased investment in safer cycling and walking infrastructure to mitigate this. The rate at which cyclists are killed or injured decreases as overall cycling numbers rise, partly because of decreased use of cars (which endanger cyclists) but also because of 'safety in numbers'. As more cyclists take to the road, they are more noticed by drivers and hence become safer (Macmillan et al, 2014).

Overall, the benefits of active transport remain positive. Longitudinal studies (ie, over time) have shown 'all-cause mortality' was 30 to 40 per cent lower in people who cycled compared to those who did not use active transport (Haines, 2012).

There is a strong link with demand management, as denser urban form and investment in infrastructure is key to encouraging the use of public and active transport (WHO 2009). A systematic review in the United Kingdom found (despite a variety of methods used) overwhelmingly positive benefit-cost ratios for investment in active transport interventions, with an average benefit-cost ratio of 5:1 (Cavill, 2008). The authors noted this was far higher than the cost-benefit ratios achieved by most transport infrastructure investments. It is also cost-effective to ensure active transport is well integrated with public transport; for example, allowing for carrying bikes on public transport (Ensor et al, 2010).

Co-benefits

The largest co-benefit of active transport appears to be more people getting their recommended 'dose' of exercise. Around half of New Zealanders currently do not meet the recommended levels of exercise (Ministry of Health, 2016). According to the *Global Burden of Disease* study, low levels of physical activity caused 1079 premature deaths (3% of the total) and the loss of 14,000 disability adjusted life years in New Zealand during 2016 (1.32% of the total). The social cost per life saved is $4.14 million (Ministry of Transport, 2017).

The risks of increased accidents and injuries can be reduced from an increased investment in infrastructure, as well as by a 'safety in numbers' effect as more people use cycling as their transport mode. However, the dominant factor for health here is the benefit of increased exercise.

Traffic congestion costs households and businesses in Auckland an estimated $0.9-$1.3 billion every year in lost time and economic activity (NZIER, 2017).

A large-scale switch to active transport could potentially avert almost all of these negative impacts. A complete shift in modes is unlikely, but even bringing other New Zealand cities up to the levels of public and active transport seen in Wellington (27.5% of trips by walking and 1.3% by bike) would create considerable benefits for both health and congestion (Shaw et al 2018).

Macmillan et al (2014) go further showing best practice investments in Auckland's cycling infrastructure could give a high return on investment (between 6 and 25 times the investment required) and results in levels of cycling seen in Europe (40% of trips by 2050).

Scale of co-benefits

The absolute scale of benefits depends on the scale of the mode shift. Given current levels of investment in active transport, Macmillan et al (2014) estimate the business as usual mode shares for cycling and light vehicles at five per cent and 75 per cent respectively in 2050[3].

That scale of mode shift would cost $630 million in infrastructure investment, but would generate considerable net benefits overall, totalling over $13 billion by 2050 (a benefit-cost ratio of 24:1). Improved exercise levels will reduce mortality; 4000 lives saved at a value of $12.4 billion. Reductions in air pollution are worth another $78 million over that time, but this is more than offset by higher levels of cyclist injuries and fatalities with a cost of $1.45 billion.

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[3] As noted above, Macmillan et al (2014) consider vehicle mode shares of up to 40 per cent and 40 per cent, respectively, as theoretically feasible in Auckland given sufficient investment in infrastructure.

In relative terms, the health impacts of any increase in active transport are likely to outweigh the emissions reductions benefits significantly. In the Macmillan et al (2014) study mentioned above, the health benefits outweighed the climate benefits by a factor of almost 12 to 1.

From the evidence scanned and reviewed, we have not found studies that look at the benefits of active transport on reduced congestion. In-house calculations suggest the congestion benefits could conservatively be at least four times the health benefits. This is clearly a large gap in the local evidence base.

Strength of evidence

The strength of evidence is strong.

Electricity for heat

The shift to electricity for heat will have some impact on reducing emissions but will also have co-benefits for health, particularly where it results in reduced burning of wood and coal in urban areas.

Intermediate pathways

The main co-benefit of electrifying heat is reducing the air pollution that results from the burning of fossil fuels and biomass. Due to burning of wood and coal, home heating is the main source of particulates in our air, while the burning of gas and coal in industrial heat generation is currently the largest source of sulphur oxides and contributes to particulate and nitrous oxide emissions (Ministry for the Environment, 2015). Air pollution causes a range of problems including respiratory and cardiovascular disease, as well as some forms of cancer (World Health Organization, 2012).

Co-benefits

Air pollution from human activity causes around 570 premature deaths per year. For a greater number of people, the more noticeable impact is days when their activity is restricted due to air pollution; the estimate is 1.35 million restricted activity days lost per annum (Ministry for the Environment & Statistics New Zealand, 2014).

Due to the range of gases and conditions involved, it is difficult to know how much different pollution sources contribute to those deaths, but in New Zealand home heating is generally considered to be the main driver, followed by motor vehicles and then industrial heat (Kuschel et al, 2012). The spatial impacts of this pollution vary, with home heating being a major driver in the south of the country and industrial heat depending on the location of factories. Shifting to electricity would entirely eliminate heat generation as a source of air pollution (with the obvious exception of any remaining fossil fuel electricity generation).

As noted under renewable electricity generation, increased deployment of renewable technology as opposed to the use of fossil fuels may bring some benefits for employment and reduced exposure to price shocks, but we have found no firm evidence on this in the New Zealand context. There are also strong links with the demand management section here – the cost of providing the electricity for heat will depend greatly on when it is needed. If industrial electricity demand for heat is at different times to the residential winter peak (which seems likely), then the cost of supplying electricity for heat could be substantially lower.

Scale of co-benefits

The total cost of deaths related to air pollution is estimated at $4.28 billion per year (Kuschel et al, 2012). For methodological reasons stated above, this is likely to be an overestimate; however, it does not include the costs of hospitalisation or restricted activity. Depending on location and time of year, heat generation is likely to be the key driver of negative heat impacts, especially during winter in southern towns and cities. A complete shift to electricity for heat could completely eradicate the contribution of heat generation to air pollution, with resulting health benefits.

A complicating factor is the composition of fuel involved. From the perspective of carbon emissions, the key concern is the burning of fossil fuels, especially coal. Of those using burners for home heating, the vast majority rely on wood compared with coal, whereas industry is far more likely to use fossil fuels to generate heat (Ministry for the Environment, 2015). Therefore, in relative terms, the benefits of switching to electricity to heat would provide far greater benefits for air pollution than it would for emissions reductions, particularly for home heating.

Strength of evidence

The strength of evidence is moderate. The quality of data on air pollution and the resulting health impacts is good, but it is difficult to attribute this to different sources.

Alternative fuels

Alternative fuels provide fewer co-benefits for air quality than the use of electricity does. While the use of biomass will provide small improvements for air pollution over fossil fuels (particularly coal), there are still some air quality impacts from burning alternative fuels. The production of alternative fuels may also offer some economic benefits in terms of employment.

Intermediate pathways

Burning fossil fuels for heat contributes to air pollution, which in turn contributes to deaths, hospitalisations and periods of restricted activity. Based on local studies (Wilton, 2014), the burning of coal as fuel, in particular, creates considerably more air pollution than wood across a range of indicators, including particulates and sulphur oxides.

While switching coal to biomass for heat is likely positive for air quality, it is worth noting that switching from electricity to biomass for heat could actually worsen local air quality outcomes.

Bioenergy (made up of biomass and biofuel) also has the potential to provide broader economic benefits, provided that it does not crowd out food production. By reducing imports of fossil fuels, increased use of bioenergy improves the resilience of our energy system to foreign price shocks, improves the trade balance and provides employment (BERL, 2011). The benefits of reduced dependency on imported fossil fuel were discussed under the electric vehicles section above. In summary, the benefits are relatively small.

Co-benefits

Switching from burning coal to biomass for heat would reduce air pollution and the associated health problems. It would not eliminate air pollution from this source entirely as biomass still emits some air pollution. There would also be some economic benefits.

Scale of co-benefits

Home heating is generally seen as the leading cause of air pollution. However, coal is used for heating by around four per cent of households compared with 37 per cent for wood (Ministry for the Environment, 2015). Therefore, the impact of a switch to biomass for home heating on air pollution is likely to be small. The size of benefits will depend on where the factories are (most coal is used in industrial plants located in rural area, away from population centres), but the gains could be of a similar scale to those from the emissions benefits (approximately $100 million per annum).

BERL (2011) has estimated that a strategy to triple levels of bioenergy use by 2040 would add 1.2 per cent to GDP (worth about $6 billion in 2010 dollars), employ 27,000 people and add $1.9 billion to the trade balance. There are also potential benefits in insulating New Zealand from overseas fuel price shocks.

Strength of evidence

The strength of evidence is moderate. The quality of data on air pollution and the resulting health impacts is good, but it is difficult to attribute this to different sources.

The net economic benefits of bioenergy are likely to be overstated as they will draw resources from elsewhere in the economy, and the air quality benefits are much smaller than for the electrification of heat.

Demand management

Demand management policies reduce the demand for activities that create emissions. This includes pricing systems such as urban form, congestion pricing and time-of-use pricing for electricity networks, ride sharing, shared community cars, avoiding trips and emissions-related pricing (eg, per kilometre insurance and registration charges).

If demand is managed well, it could take the pressure off existing electricity and roading networks, thereby reducing the costs of a transition to a low-emissions economy. While demand management does not provide large co-benefits based on available evidence, it does enable other co-benefits (such as public and active transport) and can prevent additional costs from emissions reductions policies.

Intermediate pathways

The way we design our cities has an impact on carbon emissions and quality of life. The quality and form of urban areas can either facilitate or hinder public transport. For example, the density and mix of immediate land uses and street network design can support the feasibility of public transport by increasing the number of people living within public transport catchments.

Urban sprawl increases per capita land use by 60 to 80 per cent and motor vehicle travel by 20 to 60 per cent (Litman, 2015). This leaves less land available for other uses. For example, sprawl increases the risk of high quality horticulture land near cities being converted to housing (Litman, 2015). Increases in motor vehicle travel also create external costs of air pollution (unless EV uptake is high), congestion and accidents, conservatively amounting to US$60 per tonne of carbon dioxide equivalent (t/CO_2-e) emitted by the vehicle (Global Commission on the Economy and Climate, 2015). Denser urban form and investment in public transport infrastructure are key to encouraging the use of public and active transport (WHO 2009).

Policies that encourage people to not use networks at peak times (potentially including energy efficiency, congestion pricing, time-of-use electricity pricing, ride sharing and avoiding trips) create direct savings, but can also reduce the pressure for additional investment in the network. Both electricity and transport networks are essentially built to deal with peak demand and are underutilised the rest of the time. If peak demand can be reduced, or pushed to times when the networks are underutilised, then the requirement to invest in new infrastructure is reduced. This, in turn, reduces the cost of transition to a low-emissions economy.

As an example, around 25 per cent of the investment in the electricity distribution network is used about 10 per cent of the time, and another 25 per cent is used 35 per cent of the time (Concept Consulting, 2017). That means around half the investment in electricity distribution is used less than half the time. If extra electricity demand, for example for electric vehicles or electricity for industrial heat, came at off-peak times (which is possible in both cases), then extra distribution capacity would not be needed to supply the electricity, making it much cheaper to supply. Conversely, if it came at peak times, it would require significant additional investment, increasing the cost of supplying that electricity.

Co-benefits

Urban sprawl creates benefits as well as costs, but the benefits are generally internalised, whereas a large proportion of the costs fall on other people. International evidence suggests that sprawl increases costs per person by US$4556, of which US$1988 (44%) is external, falling on other people (Litman, 2015). Therefore, dense urban planning can produce some co-benefits as well. An emphasis on 'proximity planning' can reduce emissions by making public and active transport more feasible for people, at a cost as low as $2 per tonne of CO_2-e saved (WHO, 2012).

Around one-tenth of the best horticulture land in New Zealand has been lost to housing in the past decade, contributing to the increased cost of fruit and vegetables (Hutching, 2016). The cost of this issue has not been quantified, so there are no estimates of the size of co-benefits for the food system.

Scale of co-benefits

There is limited evidence available of the scale of the co-benefits from demand management.

However, the more important issues to note with demand management are the synergies with other emissions reductions policies (eg, energy efficiency, electric vehicles, electricity for heat and active and public transport). If managed well, these synergies could reduce the costs of transition to a low-emissions economy; if managed poorly, they could increase it.

Concept Consulting (2018) has estimated the potential costs of the current electricity pricing structure on a shift to electric vehicles. If the current pricing structure stays in place then the cost of powering the electric vehicle fleet may be $4 billion higher than necessary in today's money. This is because the current pricing system gives little incentive to charge a car off peak, which could result in consumers charging their cars during peak demand periods, increasing the need for investment in electricity infrastructure.

Strength of evidence

The strength of evidence is moderate. Demand management is a complex issue that has strong synergies with other emissions reductions strategies. It is clearly an important enabler of other emissions reduction policies, but it is difficult to isolate the importance of demand management alone.

Carbon capture and storage

The co-benefits for Carbon capture and storage (CCS) are similar to those of shifting to alternative fuels, at best potentially allowing for a small reduction in air pollution. This depends very much on the technology employed.

Industrial Processes and Product Use (IPPU)

Industrial Processes and Product Use (IPPU)

From the evidence scanned for this report, no co-benefits have been identified from reducing IPPU emissions. Some relevant evidence for this sector could be indicated from the electricity to heat section noted previously.

Agriculture

Many of the proposed emissions mitigation methods for agriculture are still under development, so there is some uncertainty about their impact. At the moment, the only clear mitigation options are improved farm practices (eg, alternate feeds, lower emitting animals) and reducing livestock numbers.

Improved farm practices

Improved farm practices make more efficient use of resources, which in the context of emissions reduction usually translates into reducing inputs without reducing production (or at least without reducing profitability).

Intermediate pathways

There are considerable differences in both the financial and environmental performance of different farms even accounting for geographic differences, so there may be scope to bring more farms up to the level of the best (Anastasiadis & Kerr, 2013). Some changes to farm practices that allow for more efficient use of nutrients (particularly nitrogen) could reduce greenhouse gas emissions, at the same time reducing the nutrients leaching into our waterways, without impacting on production.

Water quality co-benefits are not completely aligned with emissions reductions and do not occur across the board. They are more likely with mitigations that reduce the use of nitrogen, which can cause both greenhouse gas emissions (nitrous oxide) and the leaching of nitrogen into waterways. Furthermore, any water quality co-benefits from greenhouse gas emission mitigation may not necessarily occur in parts of New Zealand where fresh water receiving bodies are most affected by agricultural contaminants. This will be discussed in detail in the Land Use, Land-Use Change and Forestry section.

It is worth noting that some emission mitigation options could potentially have a confounding effect, worsening water quality. Current information suggests there is not a high risk of so-called 'pollution swapping' (Shepherd et al, 2016), but this will need to be monitored as mitigation practices evolve.

Nitrogen leaching in particular has increased 29 per cent over 1990-2012, and nitrogen levels are worsening at more rivers than they are improving. In the right conditions, nitrogen can combine with phosphorus in waterways and lead to excessive algae growth (Ministry for the Environment, 2017). This is particularly a problem in streams and lakes that have lost their natural tree cover (and therefore have a higher water temperature) and/or where abstraction is reducing flows.

Co-benefits

By comparing the profitability, nitrogen leaching and greenhouse gas emissions of different farms, Anastasiadis and Kerr (2013) showed using management practices already in commercial use could potentially improve the efficiency of nitrogen use on farms. This, in turn, could potentially reduce nitrogen leaching by more than 30 per cent and greenhouse gas emissions by more than 15 per cent. The potential for such efficiency improvements varies across farms depending on their starting point. The ultimate goal is the so-called 'sweet spot' where the farmer maximises the use of low cost pasture, minimising other inputs so they can maintain production with a smaller environmental footprint.

This potential is dependent on improved management practices being implemented on-farm. Reduced nitrogen leaching will, in many catchments, lead to improved water quality as there will be a lower risk of harmful algal blooms.

Scale of co-benefits

Based on Dairy NZ's *Pastoral 21* research, it may be possible to reduce emissions and water quality problems to a certain degree without any impact on dairy farm production. By reducing nitrogen inputs (fertiliser and supplements), focusing on pasture management and maximising the output of each cow, it may be possible to reduce greenhouse gas emissions by eight per cent and nitrogen leaching by 13 per cent (Shepherd et al, 2016). Again, achieving this is dependent on the ability of farmers to implement the improved practices.

The exact value of these co-benefits will depend on the catchment; nitrogen is more of a problem in some areas than others. However, excluding the land use change elements (which will be considered below), from an environmental perspective the relative co-benefits to water quality where they exist are likely to be larger than the emissions reduction benefits. This is confirmed by economic analysis: based on nitrogen markets such as Taupō (Monge et al 2017), the relative value of nitrogen reductions is greater than those for CO_2. This outcome may be biased by the fact that nitrogen markets have only appeared in catchments where the nutrient limit is particularly acute.

Strength of evidence

Without well-formed markets for nitrogen, it is difficult to tell the relative value of these co-benefits. This makes assessing the relative size of environmental co-benefits difficult in economic terms. Nonetheless, it is clear that improved farm management practices have the potential to reduce leaching to a greater degree than greenhouse gas emissions.

New technology

There are no identifiable co-benefits from new technology to reduce methane emissions from livestock (such as selective breeding, methane inhibitors or methane vaccines). Where new technology has the potential to reduce nitrogen oxide emissions (eg, nitrification inhibitors), similar co-benefits for water quality will be expected to those set out above in 'improved farm practices'.

Livestock numbers

The final emissions mitigation available to farmers is reducing livestock numbers. In conjunction with improved farm management practices, it may be possible to reduce livestock numbers slightly without impacting on production or profitability. However, beyond this point, reduced livestock numbers would come at some cost.

Intermediate pathways

The level of some pollutants (nitrogen, phosphorus, greenhouse gases and pathogens) generally correlates to the number of animals on farm. Therefore, livestock reductions will not only reduce greenhouse gas emissions, but are also likely to reduce the water quality problems associated with livestock numbers, in particular nitrogen leaching from urine patches and pathogens from faeces.

Over the period 2009–2013, *E. coli* concentration (an indicator of pathogens) was 9.5 times higher in the pastoral class compared with the native class, but *E.coli* levels are improving at more fresh water sites than getting worse.

Some reduction in livestock numbers may be possible without harming farm production or profits. This is possible because each animal needs a certain amount of inputs just to sustain it, with any surplus going to the production of milk or meat. By maximising the output of each animal, farmers can maintain production levels with fewer animals. If production falls slightly, costs of inputs also usually fall (as per improved farm management practices), so overall profitability is not affected.

More extreme reductions in livestock numbers would continue to reduce emissions and bring water quality benefits. That would, however, come at some cost in reduced farm profits, with knock-on impacts for rural economies. This more extreme reduction in numbers may not even reduce global emissions as it could simply push production of meat and milk overseas. In economic terms, lower livestock numbers could only be justified if the resulting products were able to secure a premium. Such premiums have been seen for organic milk and products like Taupo Beef, but are yet to be proven on a large scale.

If there was reduced consumption of red meat, however, we might expect to see some health benefits. For example, a 30 per cent drop in the consumption of saturated fat in the United Kingdom is expected to reduce heart disease by 15 per cent (Watts, 2010).

There may also be some benefits of diversifying land use away from dairying and meat production, which are currently two of New Zealand's top exports. With synthetic factory meat and milk threatening to dominate the commodity market in coming years, diversification of land use could reduce the potential of a price shock hitting the New Zealand economy, similar to when nylon began to displace wool in the 1960s. The scale of such potential co-benefits is speculative and difficult to estimate.

Co-benefits

Dairy NZ's *Pastoral 21* research (discussed above) is mainly about improved farm practices, but also includes some impact from maximising the output of each cow. As noted above, it may be possible to reduce greenhouse gas emissions by eight per cent and nitrogen leaching by 13 per cent without any impact on farm profitability (Shepherd et al, 2016).

This result is dependent on the implement improved management practices on-farm. Reduced nitrogen leaching will, in many catchments, lead to improved water quality as there will be a lower risk of harmful algal blooms. Fewer animals on the land will also reduce the flow of pathogens into waterways.

In New Zealand, red meat consumption above the recommended level (leading to heart disease, stroke and colon cancer) has resulted in an estimated 4078 premature deaths each year (Springmann et al, 2016).

Scale of co-benefits

The exact value of water quality co-benefits will depend on the catchment; nitrogen and pathogens are more of a problem in some areas than others. However, in general a small reduction in livestock numbers is likely to generate larger benefits for water quality than reductions in emissions.

More extreme reductions in livestock numbers would initially continue to benefit water quality to a greater degree than emissions, but this effect would eventually reduce. In other words, the relationship between greenhouse gas emissions and nitrogen leaching of increased stocking rates is not linear. This is due to the capacity of soil to assimilate some nitrogen from animals, harnessing it to grow pasture, but beyond a certain point the nitrogen is leached. For that reason, lower stocking rates initially cause a rapid reduction in nitrogen leaching, but beyond that point nitrogen reductions become more difficult to achieve.

In terms of health benefits of reduced meat consumption, the size of any co-benefits is speculative. Domestic agricultural emissions reductions policies are unlikely to impact on the world price for meat and milk by much, so the resulting drop in consumption is likely to be small.

Strength of evidence

Without well-formed markets for nitrogen and pathogens, it is difficult to tell the relative value of these co-benefits. This makes assessing the relative size of environmental co-benefits difficult in economic terms.

The health benefits are contingent on a large reduction in New Zealand supply of meat and milk, having a large impact on local prices for these commodities, which is not likely.

Waste

Waste sector emissions

From the evidence scanned for this report, no specific co-benefits have been identified from reducing waste emissions, other than the direct financial benefits of reducing waste to landfill, freeing up resources for reuse and the ability to use land for other uses.

We note, however, the study by Blick and Comendant (2018) who investigated the emissions reduction opportunities of transitioning to a circular economy in Auckland. They estimate the emissions reductions in the waste sector from a circular economy could total 1395 kilo-tonnes of CO_2-e in 2030.

Using waste for electricity generation has the potential to lower carbon emissions, but could worsen localised air quality if direct incineration is used. Capturing the methane from anaerobic digestion of organic waste reduces emissions and minimises the air quality impacts.

Land Use, Land-Use Change and Forestry (LULUCF)

Land Use, Land-Use Change and Forestry (LULUCF)

Land-use change to forestry can have real benefits for biodiversity and water quality, as well as soaking up carbon.

Intermediate pathways

In addition to soaking up carbon, forestry has lower levels of nitrogen leaching than either sheep and beef farming or more intensive operations (such as dairy farms and some forms of horticulture). For that reason, plantation forestry has already become a major nitrogen mitigation option in catchments with severely restricted nitrogen limits, such as Taupō (Monge et al, 2017).

New Zealand has relatively high levels of erosion, losing 1.5 per cent of global sediment, despite only making up 0.2 per cent of the global land area. New Zealand's North Island has 840,000 hectares of land at risk of severe erosion. In the South Island, erosion is largely due to natural processes; but in the North, it is the result of human processes, usually the clearing of forest from hill country, and triggered by heavy rainfall (Ministry for the Environment, 2015). In certain areas of low rainfall, forestry may create spillover costs as, although it regulates water flow and controls erosion, forestry also soaks up water leaving less for the catchment below.

Many of New Zealand's indigenous species face extinction, including 81 per cent of resident bird species, 72 per cent of freshwater fish, 88 per cent of reptile, 100 per cent of frog and 27 per cent of our resident marine mammal species. Some of this is due to reduced habitat, with indigenous forest cover reduced to 30 per cent of its original extent, particularly in productive lowland habitats (Ministry for the Environment, 2015).

Many of these issues could be mitigated to some extent by land-use change to forestry. The difficulty for measuring water quality co-benefits is the strength of co-benefits is very location-specific, whereas the emissions reductions benefits are not. It does not matter where a tree is planted, if it grows it soaks up carbon. However, planting trees in specific locations like riverbanks can prevent more nutrients and soil ending up in waterways. To further complicate this, trees (as riparian planting) planted on a riverbank soaking up carbon are generally not eligible for credits under the New Zealand Emissions Trading Scheme (due to the planted area being too small).

Therefore, the co-benefits of land-use change will be highly context-specific. On lowland areas where trees are replacing intensive farming, the co-benefits of reducing nitrogen leaching are likely to be higher. On steeper land more prone to erosion, the nitrogen leaching reduction will be lower, but the co-benefits of erosion control will be greater.

In some circumstances, the co-benefits of land-use change to wetlands could be even higher than for forestry. Wetlands absorb and recycle nutrients, cleaning and regulating water flow, and also store a lot of carbon in their soils. In New Zealand, wetlands have been reduced to 10 per cent of their original extent, so their protection is important (Ministry for the Environment, 2015). However, the potential of created wetlands to act as a carbon sink is not well understood and so will not be discussed further. Much like soil carbon, until the carbon impacts of wetlands are better understood, they will not be recognised by the New Zealand Emissions Trading Scheme.

Co-benefits

Depending on the location, planting trees can have large benefits for water quality through reduced nutrient leaching and erosion. The location is also important because of what other land uses forestry is displacing.

Not surprisingly, dairy farming has a greater contribution to GDP and employment than forestry per hectare of land used. Monge et al (2017) show when nitrogen leaching and carbon sequestration are priced, the value of forestry may be competitive with dairy. This relies on a marginal price of nitrogen taken from a severely restricted catchment (Taupō), so is unlikely to be applicable across the whole country. Nonetheless, it shows forestry may be competitive with other land uses at the margin when ecosystem services are included.

However, it is unlikely the incentives provided by carbon farming alone will lead to forestry displacing dairy land in the foreseeable future. As a result, any water quality co-benefits from greenhouse gas emission mitigation may not necessarily occur in parts of New Zealand where freshwater receiving bodies are being most affected by agricultural contaminants. For example, there are not likely to be many carbon forests planted on the Canterbury Plains where the water quality is poor.

In the case of more marginal, erosion-prone land, the opportunity cost of putting this land into forestry is likely to be far lower than it is for dairy. There is an estimated 1.3 million hectares of erosion-prone land that is compliant with the Kyoto Protocol (Mason & Morgenroth, 2017). Commercial forestry already contributes more to GDP than sheep and beef farming per hectare, although not all jobs generated by forestry necessarily occur in the immediate vicinity. Any afforestation effort would certainly lead to a large one-off boost for rural economies, providing new jobs in planting and weeding. At 50,000 hectares per year such a planting effort could provide employment for 26 years. On erosion-prone land, the recent National Environmental Statement may make commercial forestry more difficult, but permanent forestry may also be an option. A mixture of mānuka honey farming and carbon farming could potentially provide alternative income sources for landowners (Weaver, 2017).

Erosion co-benefits of afforestation are likely to increase in the future. With climate change, New Zealand can expect more extreme weather events, so afforestation will also have co-benefits for adaptation by improving erosion control in areas where heavier rainfall events will happen.

Afforestation will also provide increased habitat for native species compared with pastoral agriculture, even if it is plantation of pine forest rather than native forest (Brockerhoff, 2008).

Regional councils’ response to increased afforestation will be critical. The co-benefits could be maximised if councils incentivised planting in the most sensitive catchments through extension, favourable treatment in regional plans or financial assistance.

Scale of co-benefits

Planting 1.3 million hectares of erosion-prone land with pine could make New Zealand carbon-neutral without any other mitigation efforts, but for a limited period of time. Native afforestation would absorb carbon more slowly but for a longer period of time (Mason & Morgenroth, 2017).

The value of co-benefits will depend on the exact type and location of the trees planted, and are difficult to generalise at a national level. However, Yao & Velarde (2014) give an idea of the relative values for one catchment (Ohiwa). They estimated the ecosystem value of each hectare of plantation forestry was $5600 per year. More than half of this total consists of co-benefits related to water quality, mainly reduced nutrient leaching but also including other ecosystem services such as nutrient cycling, waste treatment and water regulation. Recreation also produced notable benefits. Biodiversity benefits came next with species protection benefits valued at $257 per hectare and pollination at $206 per hectare. Erosion control was valued at $121 per hectare.

Exact numbers will vary depending on the characteristics of each catchment, but even a conservative estimate of the nationwide impact shows the relative scale of the benefits from afforestation for water quality are higher than they are for carbon (which was valued at $250 per hectare at current emissions prices).

NZ Carbon Farming also commissioned Infometrics to estimate the economic benefit of afforestation. Infometrics estimates 1000 new jobs for every 50,000 hectares of planting.

Strength of evidence

The strength of evidence is moderate. There are clearly strong co-benefits from land use change and afforestation, but the scale and mix of those benefits will vary greatly depending on when, where and which trees are planted.

Conclusion

It is difficult to compare the size of co-benefits for different policies, given they have been estimated with vastly different methodologies. The best method we have of comparing is the relative size of co-benefits compared with emissions reductions benefits.

The areas with relatively large co-benefits are more likely to have significantly different benefit cost ratios for investment if the co-benefits are included.

Table 1 summarises the evidence in this paper on the scale of the co-benefits relative to the emissions reductions for the main policy objectives. It also notes the main sources of those co-benefits.

Table 1: Summary of co-benefits relative to emissions reductions

	Size of co-benefits relative to emissions reductions		
Sector	Low	Medium	High
Energy	Alternative fuels Electric vehicles Renewable electricity Demand management CCS	Electricity for heat **H**	Energy efficiency **H** Freight to rail **C H** Public transport **C H** Active transport **H C**
IPPU			
Agriculture	New technology (methane)	Farm practices **W** Livestock numbers **W**	
LULUCF			Forestry **W B**
Waste	Reduce Reuse		

Co-benefits key: Health = **H**; Congestion = **C**; Biodiversity = **B**; Water quality = **W**

This work has identified energy efficiency, freight to rail, public transport, active transport and forestry as the major potential areas of co-benefits. The recommendation is that these policy areas are the priority for including co-benefits in any benefit-cost analysis. Electricity for heat, improved farm practices and reduced livestock numbers would be the next areas of focus. However, it is worth noting that demand management is a key enabler for energy efficiency, freight to rail, public transport and active transport; therefore, it is also a strong contender for inclusion.

In terms of further research, the most noticeable gap in the current evidence base is the co-benefits of active transport in relation to congestion. In general, more effort needs to go into ensuring co-benefit estimates are methodologically rigorous (eg, looking at disability adjusted life years rather than mortality rates for health benefits) and more consistent to allow for reasonable comparisons.

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