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NORTH HERTFORDSHIRE DISTRICT COUNCIL

CABINET PANEL ON THE ENVIRONMENT

THURSDAY, 5TH MARCH, 2020

SUPPLEMENTARY AGENDA

Please find attached supplementary papers relating to the above meeting, as follows:

Agenda No	Item
4.	**PUBLIC PARTICIPATION (Pages 3 - 112)**

To receive petitions, comments and questions from the public.

Please note that speakers should register their interest to speak by midday two days before the meeting.

The Chairman has requested that a written submission of the content/subject of the presentation be submitted to committee.services@north-herts.gov.uk by the above deadline.

Those selected to make presentations will be advised the day before the meeting.

Please find attached submissions by members of the public.

The following will be speaking at the meeting:

- Gilly Chegwyn
- Rod Hart
- Julia Sonander – Transition Towns Letchworth

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AIR POLLUTION AND HEALTH

Notes by Gill Langley[1] PhD for XRNH

January 2020

Some health effects associated with air pollution are well recognised, such as increases in hospital admissions and deaths from cardiovascular diseases, respiratory diseases and lung cancer. People with pre-existing cardiovascular and respiratory diseases and older people are particularly at risk.

Now, researchers are finding that air pollution may be associated with a much wider range of health conditions, including diabetes and neurological disease, as well as exposure during pregnancy being associated with miscarriages, low birth weight and pre-term births. Much new research has been published in the last year.

Toxic air pollution (fine particulates, PM; and nitrogen dioxide, NO_2) causes more than 40,000 deaths in Britain each year[2]. The Royal College of Physicians and the Royal College of Paediatrics and Child Health state:

> "In most cases legislated concentration limits do not represent a 'safe' level for the population as a whole, but are often talked about as levels considered to not pose a 'significant risk' to health. This begs the question of the meaning of 'significant' – given, for example, that impacts of exposure to fine particles have been observed at very low concentrations and that there is no evidence for a threshold for exposure at the population level".

Public Health England has estimated that health effects from air pollution cost the NHS and social care services more than £40 million annually[3].

1

[1] Gill Langley has a first degree and a PhD in neurochemistry from Cambridge University. She was the science director of a medical research charity for 30 years, and has been an adviser to the European Union on toxicology and toxicity testing.

2

[2] Royal College of Physicians/Royal College of Paediatrics and Child Health (2016). Report: Every breath we take: the lifelong impact of air pollution. file:///C:/Users/GILLAN~1/AppData/Local/Temp/Air_pollution_main%20report_WEB_1_0_0.pdf

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[3] Public Health England (2018). Estimation of costs to the NHS and social care due to the health impacts of air pollution. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/708855/Estimation_of_costs_to_the_NHS_and_social_care_due_to_the_health_impacts_of_air_pollution_-_summary_report.pdf

Of the 29,000 deaths annually from exposure to $PM_{2.5}$ in the UK, the Committee on the Medical Effects of Air Pollutants (COMEAP) estimates only a small fraction relate to exposures in excess of legal limits[4]. This means we **must** get levels of $PM_{2.5}$ much lower than they are in North Hertfordshire.

Levels of NO_2 have been illegally high in most urban areas of Britain since 2010, and Hitchin is no exception. The annual average AQO for NO_2 has been regularly exceeded at Paynes Park and Stevenage Road in Hitchin[5]. There are aspirations but no real action from NHDC to encourage walking and cycling but experience indicates little will come of these in terms of reducing traffic movements. We only know levels of air pollution where monitors are installed – they may be higher elsewhere.

ADULTS

Lung cancer

Higher exposures to $PM_{2.5}$ and PM_{10} cause higher risk of lung cancer in adults[6].

Asthma & respiratory diseases

Studies in several cities in Britain show adults are 1.4 – 2.1% more likely to be admitted to hospital for asthma on days with high NO_2 pollution.[7]

Even relatively low traffic-related air pollution increase risks of respiratory and allergic airways problems in susceptible people[8].

Dementia

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[4] COMEAP. The mortality effects of long-term exposure to particulate air pollution in the United Kingdom. London: Health Protection Agency, 2010. www.gov.uk/government/publications/comeap-mortality-effects-of-long-term-exposure-to-particulate-air-pollutionin-the-uk

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[5] NHDC. Local Air Quality Management Annual Status Report 2018.

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[6] Raaschou-Nielsen O, et al. (2013). Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). Lancet Oncology 14(9):813-22.

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[7] Evangelopoulos, D et al (2019). Personalising the Health Impacts if Air Pollution: Interim Statistics Summary for a Selection of Statements. Report by King's College London. http://www.erg.kcl.ac.uk/Research/home/projects/personalised-health-impacts.html

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[8] Bowatte G, et al. (2017). Traffic-related air pollution exposure is associated with allergic sensitization, asthma, and poor lung function in middle age. Journal of Allergy & Clinical Immunology 139(1):122-129.

Air pollution is linked to a higher chance of developing dementia (Alzheimer's and vascular dementia) according to a 2018 study by London University researchers[9]. At all ages people's health was at risk from breathing dirty air, but the research found that people over 50 in areas with the highest levels of NO_2 had a 40% greater risk of developing dementia than those with the least NO_2 pollution. Increases in dementia risk were also observed with $PM_{2.5}$ specifically from traffic sources. When compared to people living outside London, with clean air, presumably the difference in risk would be even greater. The link between higher pollution and higher levels of dementia could not be explained by any other risk factors.

Long-term exposure to PM_{10} is associated with loss of mental ability, in maths and verbal tests, in older people[10].

Diabetes

A meta-analysis which included three studies on $PM_{2.5}$ and four studies on NO_2, showed an 8–10% increased risk of type 2 diabetes per 10 μg/m^3 increase in exposure to both pollutants, with stronger associations being observed in women[11].

Heart attack and strokes

A 10-year study of air pollution exposure and coronary artery calcification (hardening of the arteries) showed that $PM_{2.5}$ and $NO_2$are strong risk factors for atherosclerosis[12]. Nearly 7,000 people were monitored in six US cities with traffic-pollution levels commonly seen around the world. Moving house from a low-pollution rural area to a high-pollution metropolitan area would cause atherosclerosis to increase 38% faster every year.

According to an October 2019 report from King's College London, people of all ages are at higher risk of heart attack on high air pollution days than lower pollution days, related to $PM_{2.5}$ particles[13]. Each year on average, high air pollution days in London are responsible for 87 more cardiac arrests.

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[9] Are noise and air pollution related to the incidence of dementia? A cohort study in London, England Iain M Carey et al. BMJ Open. 2018; 8(9): e022404.

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[10] Zhang X, Chen X, Zhang X. (2018). The impact of exposure to air pollution on cognitive performance. Proceedings of the National Academy of Sciences U S A. 115(37):9193-9197.

11

[11] Eze IC, et al. (2015). Association between ambient air pollution and diabetes mellitus in Europe and North America: systematic review and meta-analysis. Environmental Health Perspectives 123:381–9.

12

[12] Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. Kaufman JD et al. (2016). Lancet 388(10045):696-704.

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The risk of emergency hospitalisation for stokes is greater on high air pollution days, by 3.9% in Derby, for example. This is related to NO_2 levels. In London, more people are admitted to hospital for strokes on high air pollution days than on low pollution days, and these strokes could be prevented by lowering NO_2 air pollution. Living near a busy road in London increases risk of hospitalisation for strokes by 6.6%.

BABIES AND CHILDREN

Children are even more susceptible to air pollution than adults.

Miscarriage, stillbirths and premature births

Long-term and short-term exposure to traffic pollution increases the risk of miscarriages. A 2019 paper shows a 10-ppb increase in 7-day average levels of NO_2 increases the risk of spontaneous miscarriage by 16% [14]. This is akin to the number of miscarriages caused by smoking during pregnancy. The average seven-day NO_2 level in the week preceding the miscarriages was 34 micrograms per cubic metre (µg/m^3) of air – the air quality objectives that NHDC works to are: 200 µg/m^3 not to be exceeded more than 18 times a year for one hour, and an annual mean of 40 µg/m^3. This means that some women in North Hertfordshire have definitely experienced a miscarriage caused by traffic pollution.

A study of more than half a million births and stillbirths in London suggest that exposure to higher levels of ozone (O_3) and traffic non-exhaust $PM_{2.5}$ (from brakes and road dust) during pregnancy may increase risk of preterm birth and stillbirth[15]. An increase in O_3 exposure was associated with higher risk of preterm birth, all-cause stillbirth, and with 22% increased odds of asphyxia-related stillbirth. $PM_{2.5}$ was associated with 3% increased odds of preterm birth and 7% increased odds of stillbirth.

Low birth weight

Living near busy roads contributes to low birth weights in babies. According to which city has been analysed, the risk of low birth weight is increased by 0.1 – 0.4% with high NO_2 pollution[16].

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[13] Evangelopoulos, D et al (2019). Personalising the Health Impacts if Air Pollution: Interim Statistics Summary for a Selection of Statements. Report by King's College London. http://www.erg.kcl.ac.uk/Research/home/projects/personalised-health-impacts.html
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[14] Leiser CL, et al. (2019). Acute effects of air pollutants on spontaneous pregnancy loss: a case-crossover study. Fertility & Sterility 111(2):341-347. Summary only: https://www.ncbi.nlm.nih.gov/pubmed/?term=fuller+m+utah+miscarriage+pollution&report=abstract
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[15] Smith RB, et al. (2020). Impacts of air pollution and noise on risk of preterm birth and stillbirth in London.
Environ Int. 134:105290.
https://www.sciencedirect.com/science/article/pii/S0160412019314734?via%3Dihub
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[16] Evangelopoulos, D et al (2019). Personalising the Health Impacts if Air Pollution: Interim Statistics Summary for a Selection of Statements. Report by King's College London. http://www.erg.kcl.ac.uk/Research/home/projects/personalised-health-impacts.html

Infant mortality

In 2019, research into air pollution in Britain was reported that looked at the births and deaths of 8 million babies[17]. The study found that exposure to air pollution from road traffic is associated with reductions in children's lung functions as early as the first trimester of pregnancy. In the most pollutes areas, the risk of post-neonatal deaths increased by 11% for NO_2 and 12% for PM_{10}. The risk of deaths in infancy increased by 7% for NO_2 and 4% for PM_{10}.

Brain and cognition

Traffic-related air pollution has been linked to poorer cognitive (brain) development in young children[18], and continued significant exposure may produce neuroinflammation and altered brain immune responses in early adulthood.[19]

Reduced lung growth and poor lung function

Many research studies have shown the damage caused to children's lungs by traffic pollution. Roadside NO_2 pollution stunts lung growth in children by 7.7% in Birmingham and by 12.5% in London[20]. This lack of growth is permanent and cannot be remedied at an older age. Living near busy roads contributes to a 4.7% (Birmingham) and an 8.7% (London) greater chance of reduced lung function in children over the long term.

Asthma

Four million children develop asthma every year worldwide as a result of NO_2 pollution from traffic[21]. About 92% of paediatric asthma cases attributable to NO_2 exposure occurred in areas with annual

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[17] European Lung Foundation International Congress (2019). Abstract no: PA297, "Effects of air pollution on all cause neonatal and post-neonatal mortality: population based study", by Sarah Kotecha et al.

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[18] Sunyer J et al. Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study. PLoS Medicine 2015;12:e1001792 10.1371/journal.pmed.1001792

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[19] Calderón-Garcidueñas L et al. Long-term air pollution exposure is associated with neuroinflammation, an altered innate immune response, disruption of the blood-brain barrier, ultrafine particulate deposition, and accumulation of amyloid beta-42 and alpha-synuclein in children and young adults. Toxicol. Pathol. 2008;36:289–310. 10.1177/0192623307313011

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[20] Evangelopoulos, D et al (2019). Personalising the Health Impacts if Air Pollution: Interim Statistics Summary for a Selection of Statements. Report by King's College London. http://www.erg.kcl.ac.uk/Research/home/projects/personalised-health-impacts.html

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average NO_2 concentrations lower than the WHO guideline of 21 parts per billion. According to the researchers, the adequacy of the WHO guideline for NO_2 concentrations might need to be revisited.

In London, a child is 4.2% more likely to be admitted to hospital for asthma on days with high NO_2 pollution, compared to days when pollution is lower. Increases in hospitalisation of children occur in all cities studied so far[22].

High PM_{10} particle pollution causes exacerbation of cough, wheezing and breathlessness in asthmatic children[23].

According to research funded by UNICEF, "Every day, millions of our children are exposed to dangerous levels of pollution in the areas where they live, learn and play" [24]. Children are disproportionately exposed to air pollution while on the school run and in the school playground. PMs are highly dangerous, as they can penetrate deep into the lungs and into the brain.

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[21] Achakulwisut P, et al. (2019). Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO_2 pollution: estimates from global datasets.Lancet Planetary Health. 3(4):e166-e178. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(19)30046-4/fulltext
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[22] Evangelopoulos, D et al (2019). Personalising the Health Impacts if Air Pollution: Interim Statistics Summary for a Selection of Statements. Report by King's College London. http://www.erg.kcl.ac.uk/Research/home/projects/personalised-health-impacts.html
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[23] Evangelopoulos, D et al (2019). Personalising the Health Impacts if Air Pollution: Interim Statistics Summary for a Selection of Statements. Report by King's College London. http://www.erg.kcl.ac.uk/Research/home/projects/personalised-health-impacts.html
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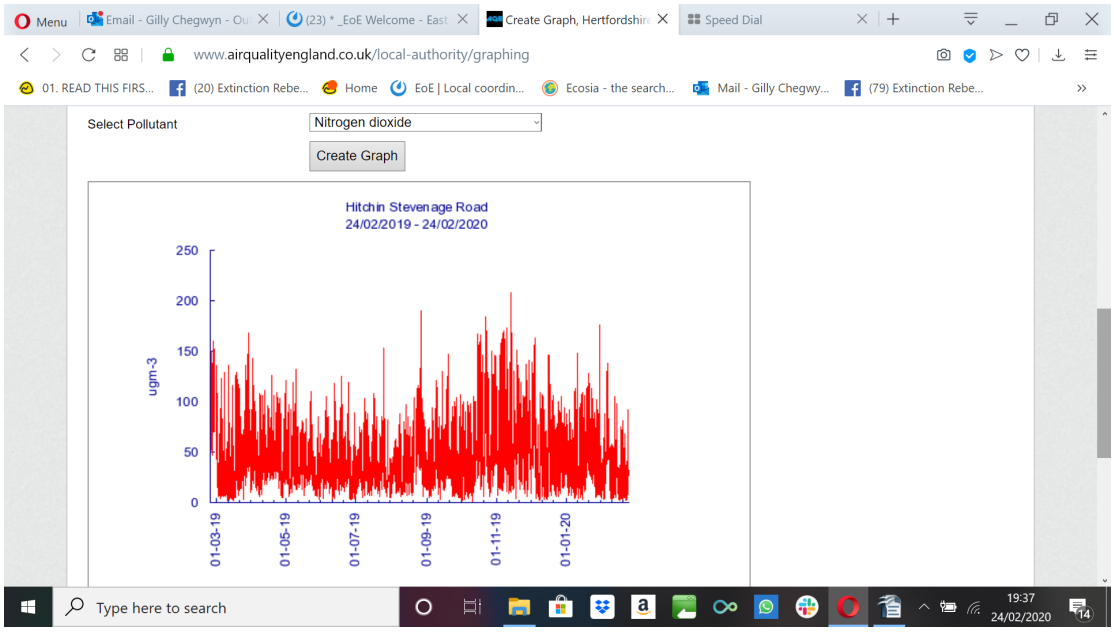
[24] The Toxic School Run, a Unicef UK Research Briefing by Harriet Edwards (Unicef) and Abigail Whitehouse (Queen Mary's University London). September 2018.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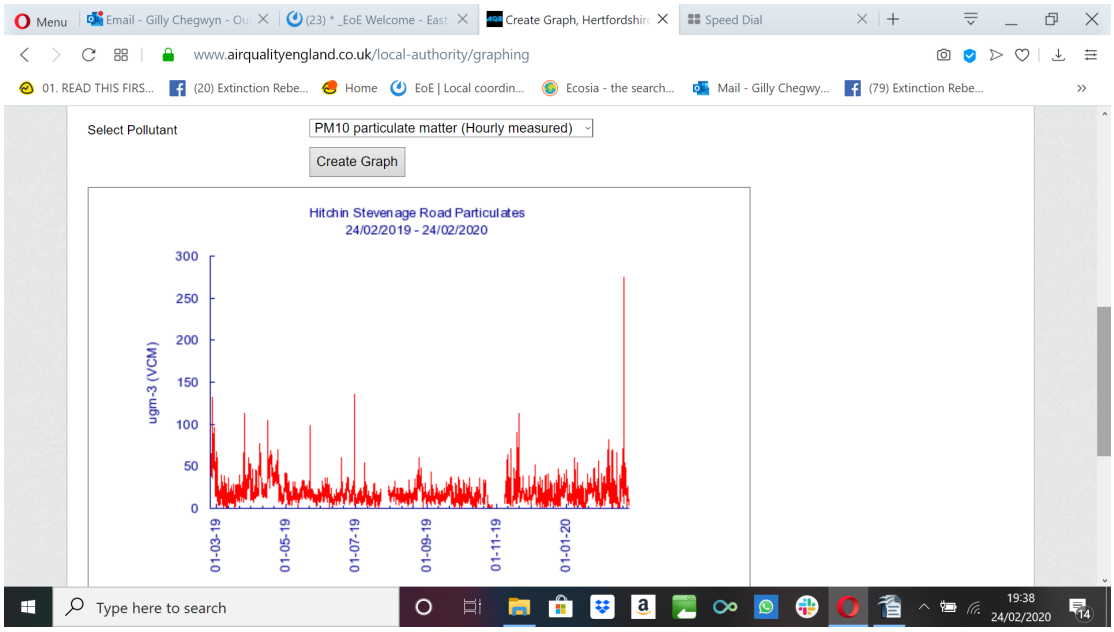
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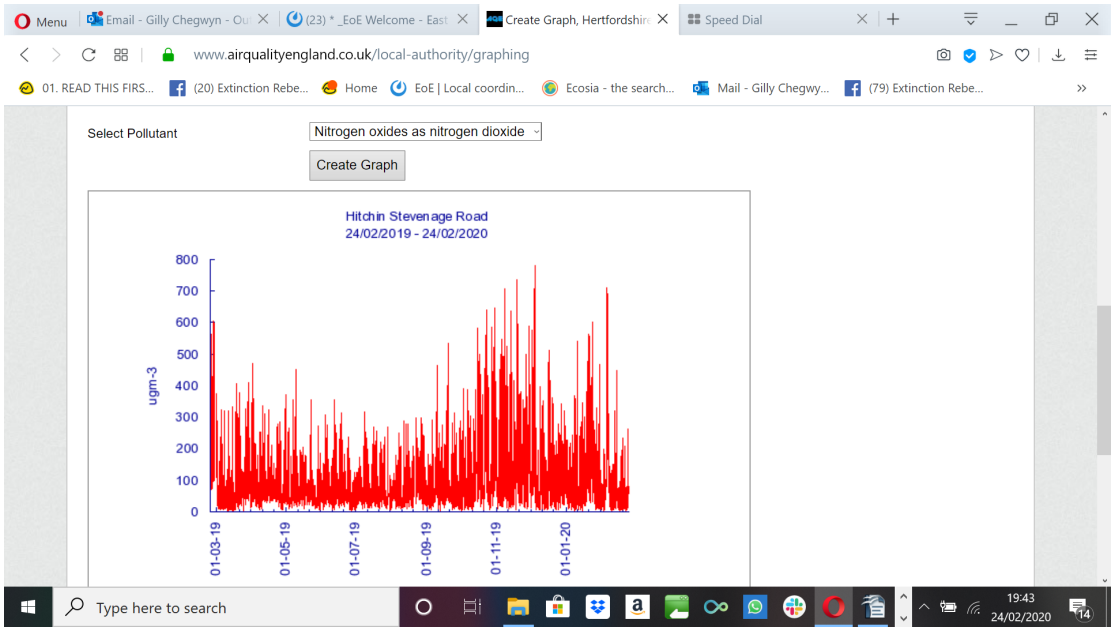
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In North Herts District transport generates 43% of CO2 emissions I'd like to talk to you today about how that can be reduced quickly, easily and cheaply.

1. There are two existing laws prohibiting the idling of vehicles on a public highway whilst stationary:

Rule 123 of the Highway Code, Reg 98 of the Road Vehicles Regulations 1986, Road Traffic (vehicle emissions) Regulations 2002 and section 87 of the 1995 Environment Act

These laws must be strictly enforced using fixed penalty notices or spot fines. This will provide a revenue stream for the local authority. Of particular relevance and importance outside schools, sports centres, doctors surgeries, parades of shops, stations, supermarket car parks and other places where are pedestrians are present. No idling in taxi ranks and by bus drivers also need to be strictly enforced, this has both health benefits and emissions reductions benefits.

2. Stop paying mileage allowance to members on official business including attending meetings unless they have an ultra low emissions vehicle, effective immediately. Apply the same criteria to officers effective September 2020. This could be incentivized by the provision of secure cycle storage and a half an hour allowance at the beginning of the working day day to shower and change, with perhaps an additional half day annual leave for every 100 days of cycling or walking to work?Incrementally increasing, with time, parking charges will be levied at all council buildings for non-ULEVs. The resulting savings and revenues shall be used to provide secure cycle accommodation and shower facilities in council property. Sufficient ULEV charging points shall be provided at all council premises, charging fees will be levied at cost.

3. There are almost no electric vehicle charge points on council property why is this? Initially council owned properties should immediately be provided with electric vehicle recharge points after that provision should be made for EV charge points for residents who need to street park.

4. Conversion to ultra low emissions of council run fleet vehicles this needs to happen very rapidly and there should be a plan showing the date by which all vehicles will be converted to to ultra low emissions.

5. Public transport providers operating within the district (buses, taxis et cetera) shall be encouraged to replace their existing vehicles with electric where feasible, or other low carbon vehicles where not, using licensing and tax incentives or disincentives for non-compliance effective immediate to complete by 2025. The aim should be to make all public transport in the district free of charge, with a target date of 2025.

6. Encouragement for businesses and residents to transition to ultra low emission vehicles or to no private vehicle ownership at all. Businesses that encourage their employees to use ultra low emissions vehicles, public transport or walking/cycling to work could be given business rates relief. Effective immediate.

7. Citizens shall be incentivised to run ULEVs, by a reduction in council tax and grants for the installation of residential EV charge points. Costs to be recovered over nn years, funded by a reduction in private vehicle ownership costs.

8. All council run car parks shall double their car parking charges for non-ULEVs effective immediate, and thereafter incrementally increasing scale of charges shall be levied. ULEV parking will be free. A similar scheme shall be applied to privately owned car parks, schools, hospitals, supermarkets etc

with incentives and disincentives via business rates. Supermarkets shall be encouraged to run free, local public transport schemes using low carbon vehicles.

9. Schools that have a walk or cycle to school policy shall be measured and rewarded against student numbers walking or cycling to school. Schools that have no such policy will be penalised.

10. New residential development should be based on the concept of community/localism and where necessary the use of public transport. No off-road parking provision should be made and on-road parking should be severely restricted.

Presentation to NHDC Environmental Panel on Transport

We believe every town in North Hertfordshire should have a sustainable travel town plan.

For those towns who do not have a town council to produce this plan an appropriate forum should be set up to undertake this exercise, including local resident representatives.

It is clear that funding for transport is tight and it is therefore important that we maximise the benefit from the funds available which may be best achieved through many of lower cost schemes rather than a few high cost show projects.

TTL would be happy to contribute to the development of a sustainable travel town plan for Letchworth. An initial set of ideas for what this might include is provided in the short presentation that follows.

Walking

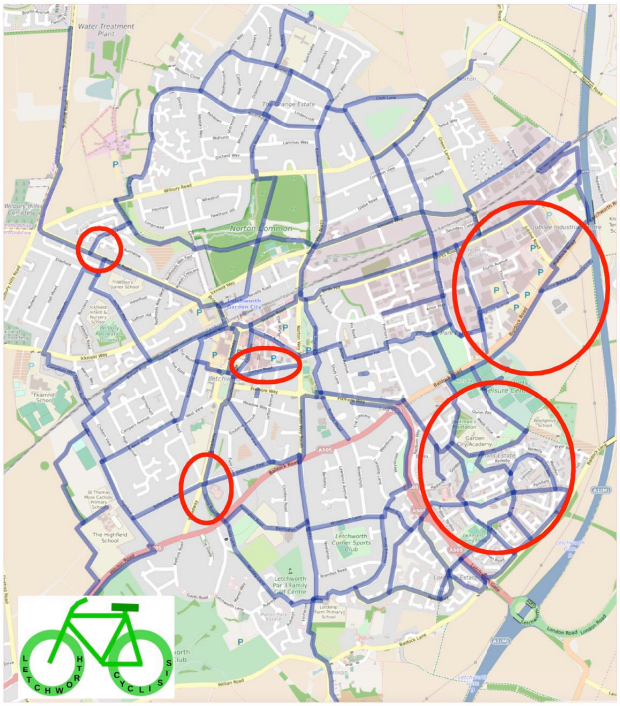
Letchworth would benefit from more Pedestrian Crossings, particularly on busy roads on schools routes. e.g. onto Broadway Gardens, across Bridge Road, across Broadway linking to the south side of Spring Road, from Jackman's to Pixmore Way by St Paul's Church.

Letchworth would benefit from some paths being widened so they can be used with a pushchair or wheelchair. E.g.
Lytton Avenue and Souberie Avenue

On-road parking should be prevented where it forces pedestrians into road to check for traffic. E.g. Pixmore Way where it links to Gernon Way

More direct Routes
Railway Line has limited crossing points
Lots of dead-ends on industrial estate
Shopping Centre / Arcade closures at night blocks off cross-town routes

Cycling



"In Hertfordshire cycling has a low mode share (1.7% for trips less than 1 mile, 4.8% for trips of 3-5 miles, 3.1% for trips of 3-5 miles)."

To encourage more people to use bicycles, it is important that there are cycle routes in Letchworth Garden City which are both safe and reasonably direct. A proposed network of cycle friendly roads and cycle lanes has been identified taking into account key destinations within and from each neighbourhood in the town.

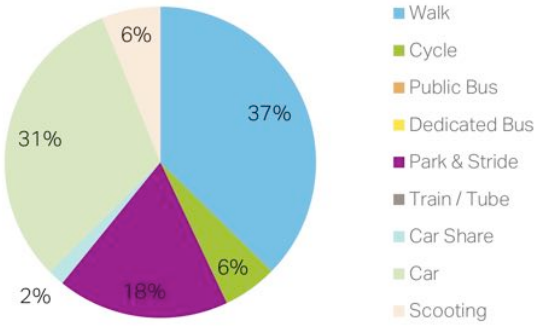
Letchworth cyclists have identified five beneficial schemes which could be delivered in advance, yet be compatible with, a complete network.

- First Garden City Roundabout
- Gernon Road
- Jackman's Cycle Paths
- Bedford Road Crossing
- Leisure Centre

School Trips

"avoidable car trips increase local highway congestion and picking up and dropping off pupils creates safety risks around schools". North Central Hertfordshire Growth and Transport Plan

Letchworth Garden City



The percentage where the car represents at least part of the school journey is 51%.

In North Central Herts:

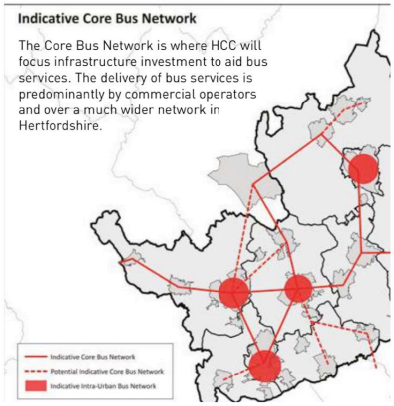
- Letchworth is the town with the highest percentage of children whose school travel mode is car (31%) and Hitchin is the lowest (17%).
- Baldock and Stevenage both have average walking mode shares of 50% for school trips compared to 37% in Letchworth.
- The average mode share for public bus is 11% and for rail 10% for schools in Hitchin, but negligible in other towns.
- The average mode share for cycling in Hitchin is 2%, while this varies between 6% and 8% in the other towns.
- Car sharing is not popular.

TTL/ Sustrans have scoped a project to use an innovate modular road planning kit around school entrances and on school routes to explore if different road layouts could encourage more children to switch to sustainable travel modes. We would like to work with NHDC / HCC to access funding for this project, which should deliver both local solutions and valuable learning for all of Hertfordshire.

Public Transport – Trains and Buses

Letchworth Rail Service

- Ensure Fast Services to London
- Good connections to and from Stevenage to pick up East Coast mainline
- Efficient links to new Oxford - Cambridge line
- Sufficient capacity on trains
- Appropriate fares which compete with car travel
- Ticketing for different working patterns, e.g. part time working season ticket
- Taking bikes to Cambridge / Stevenage on train



Buses

- Need fast, reliable links to Stevenage, Baldock, Hitchin and Luton Airport and from housing to station and schools.
- Pricing must be competitive with using a car.
- Possibility of booking seats may improve confidence
- Explore introduction of 'Taxishare' service

'Taxi-share' - Timetabled like a bus service, but a taxi or private hire vehicle is used. Passengers must book the day before trip and the service will only run if someone books to travel. Passengers get picked up from their nearest bus stop or in some cases from their home address.

Public Transport Interchange

"A core feature of our plan is to do more to improve conditions for sustainable modes…. It will include a more prominent consideration of their needs in all transport schemes, strategies and new developments as well as improvements to cycling infrastructure, walking environments and multi modal interchanges." LTP4

Letchworth has a small Station Car Park on south side of railway line with limited small roads crossing railway (much of existing housing and planned new housing is North of the railway line). There is extensive parking on local roads by commuters leading to congestion and safety issues.

Redesign of Railway Interchange:

- Cycling / walking bridge,
- Bus station outside the train station (moving war memorial),
- Entrance to station from either side of railway without using Nevilles Bridge
- Off-road Car Parking accessible from the North Side of town?

Letchworth Road Design Improvements

Project to tackle on-street parking:

- one way system through roads where parking has already made streets single lane (e.g. Cowslip Hill, Ridge Avenue)
- Inset parking bays on core routes or elements of cycle network
- Review Heritage Foundation planning restrictions for terraced housing
- Parking restrictions to encourage use of driveways and garages
- Support for housing associations and guidance for residents to construct ‘green’ driveways

Ensure major routes into town (A505, Pixmore Way, Norton Way, Bedford Road, Icknield Way, Green Lane) are free of obstructions.

Redesign of Icknield Way / Norton Way Mini - Roundabouts.

A future for the world's children? A WHO-UNICEF-*Lancet* Commission

Helen Clark, Awa Marie Coll-Seck*, Anshu Banerjee, Stefan Peterson, Sarah L Dalglish, Shanthi Ameratunga, Dina Balabanova, Maharaj Kishan Bhan†, Zulfiqar A Bhutta, John Borrazzo, Mariam Claeson, Tanya Doherty, Fadi El-Jardali, Asha S George, Angela Gichaga, Lu Gram, David B Hipgrave, Aku Kwamie, Qingyue Meng, Raúl Mercer, Sunita Narain, Jesca Nsungwa-Sabiiti, Adesola O Olumide, David Osrin, Timothy Powell-Jackson, Kumanan Rasanathan, Imran Rasul, Papaarangi Reid, Jennifer Requejo, Sarah S Rohde, Nigel Rollins, Magali Romedenne, Harshpal Singh Sachdev, Rana Saleh, Yusra R Shawar, Jeremy Shiffman, Jonathon Simon, Peter D Sly, Karin Stenberg, Mark Tomlinson, Rajani R Ved, Anthony Costello*

Executive summary

Despite dramatic improvements in survival, nutrition, and education over recent decades, today's children face an uncertain future. Climate change, ecological degradation, migrating populations, conflict, pervasive inequalities, and predatory commercial practices threaten the health and future of children in every country. In 2015, the world's countries agreed on the Sustainable Development Goals (SDGs), yet nearly 5 years later, few countries have recorded much progress towards achieving them. This Commission presents the case for placing children, aged 0–18 years, at the centre of the SDGs: at the heart of the concept of sustainability and our shared human endeavour. Governments must harness coalitions across sectors to overcome ecological and commercial pressures to ensure children receive their rights and entitlements now and a liveable planet in the years to come.

Invest in children's health for lifelong, intergenerational, and economic benefits

The evidence is clear: early investments in children's health, education, and development have benefits that compound throughout the child's lifetime, for their future children, and society as a whole. Successful societies invest in their children and protect their rights, as is evident from countries that have done well on health and economic measures over the past few decades. Yet many politicians still do not prioritise investing in children, nor see it as the foundation for broader societal improvements. Even in rich countries, many children go hungry or live in conditions of absolute poverty, especially those belonging to marginalised social groups—including indigenous populations and ethnic minorities. Too often, the potential of children with developmental disabilities is neglected, restricting their contributions to society. Additionally, many millions of children grow up scarred by war or insecurity, excluded from receiving the most basic health, educational, and developmental services.

Decision makers need a long-term vision. Just as good health and nutrition in the prenatal period and early years lay the foundation for a healthy life course, the learning and social skills we acquire at a young age provide the basis for later development and support a strong national polity and economy. High-quality services with universal health-care coverage must be a top priority. The benefits of investing in children would be enormous, and the costs are not prohibitive: an analysis of the SDGs suggests a financing gap of US$195 per person. To ensure stronger economic and human development, each government must assess how to mobilise funding using instruments that help the poorest proportion of the population to meet this gap for children, and frame these as the most powerful investments a society can make. But investments are not just monetary: citizen participation and community action, including the voices of children themselves, are powerful forces for change that must be mobilised to reach the SDGs. Social movements must play a transformational role in demanding the rights that communities need to care for children and provide for families.

Government has a duty of care and protection across all sectors

Countries that support future generations put a high priority on ensuring all children's needs are met, by delivering entitlements, such as paid parental leave, free primary health care at the point of delivery, access to healthy—and sufficient amounts of—food, state-funded or subsidised education, and other social protection measures. These countries make sure children grow up in safe and healthy environments, with clean water and air and safe spaces to play. They respect the equal rights of girls, boys, and those with non-conforming gender identities. Policy makers in these countries are concerned with the effect of all policies on all children, but especially those in poorer families and marginalised populations, starting by ensuring birth registration so that the government can provide for children across the life course, and help them to become engaged and productive adult citizens. The rights and entitlements of children are enshrined within the UN Convention on the Rights of the Child (CRC) ratified by all countries, except the USA. Countries might provide these entitlements in different ways, but their realisation is the only pathway for countries to achieve the SDGs for children's health and wellbeing, and requires decisive and strong public action.

Since threats to child health and wellbeing originate in all sectors, a deliberately multisectoral approach is needed to ensure children and adolescents survive and thrive from the ages of 0–18 years, today and in the future. Investment in sectors beyond health and education—such as housing, agriculture, energy, and transport—are

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needed to address the greatest threats to child health and wellbeing. Political commitment at executive level is needed to coordinate across sectors and leverage synergies across the life course, ensuring universal health coverage; good nutrition and food security for all; thoughtful urban planning; safe and affordable housing and transport; clean energy for all; and equitable social welfare policies. Multisectoral governance might take different forms in each country, but it will require strategic partnerships, cabinet-level coordination across ministries, and management of diverse partners, with clear roles for each, including for non-state actors and the private sector. Heads of state or prime ministers must designate a cross-cutting government ministry or equivalent to ensure joined-up action and budgeting for pro-child policies and to demand harmonised assistance from global stakeholders, whose support is currently fragmented and inefficient.

Measure how children flourish today, but also how countries' greenhouse gas emissions are destroying their future

Wealthy countries generally have better child health and development outcomes, but their historic and current greenhouse gas emissions threaten the lives of all children. The ecological damage unleashed today endangers the future of children's lives on our planet, their only home. As a result, our understanding of progress on child health and wellbeing must give priority to measures of ecological sustainability and equity to ensure we protect all children, including the most vulnerable. We assessed the feasibility of monitoring countries' progress through a new child flourishing and futures profile, developed on the basis of survive and thrive SDG indicators reported by 180 countries, territories, and areas (hereafter referred to as countries), and future threats to children's wellbeing using the proxy of greenhouse gas emissions by country. We also complemented the profile with existing measures of economic equity. The poorest countries have a long way to go towards supporting their children's ability to live healthy lives, but wealthier countries threaten the future of all children through carbon pollution, on course to cause runaway climate change and environmental disaster. Not a single country performed well on all three measures of child flourishing, sustainability, and equity.

The SDG indicators already provide a strong foundation for monitoring progress. However, we only found a very small amount of country data for the indicators used to track child health and wellbeing, which all countries agreed to collect. SDG monitoring needs a strong boost in investment to bridge the large data gaps in key indicators (with <50% of countries reporting data for many indicators), to allow for subnational disaggregation if governments are to monitor, review, and act. To ensure our children grow and flourish, we require timely and accurate population data on health, nutrition, educational access and performance, housing, and environmental security, among other entitlements. Harnessing the power of citizen accountability mechanisms will be essential to fill the data gaps. We also propose the development of user-friendly country dashboards to assess the effects on children's wellbeing and sustainable development. Given the urgency for action, regular reports on the SDGs to the UN General Assembly must be the anchor of strong advocacy on action for children everywhere.

Adopt a new protocol to the UN CRC to regulate against commercial harm to children

Although we recognise the role business plays in wealth and job creation, the commercial sector's profit motive poses many threats to child health and wellbeing, not least the environmental damage unleashed by unregulated industry. More immediately, children around the world are enormously exposed to advertising from business, whose marketing techniques exploit their developmental vulnerability and whose products can harm their health and wellbeing. Companies make huge profits from marketing products directly to children and promoting addictive or unhealthy commodities, including fast foods, sugar-sweetened beverages, alcohol, and tobacco, all of which are major causes of non-communicable diseases. Children's large and growing online exposure, while bringing benefits in terms of information access and social support, also exposes them to exploitation, as well as to bullying, gambling, and grooming by criminals and sexual abusers.

Industry self-regulation does not work, and the existing global frameworks are not sufficient. A far stronger and more comprehensive approach to regulation is required. We call for the development of an Optional Protocol to the CRC (ie, an additional component to the treaty that must be independently ratified), to protect children from the marketing of tobacco, alcohol, formula milk, sugar-sweetened beverages, gambling, and potentially damaging social media, and the inappropriate use of their personal data. Countries who have led the way in protecting children from the harms of commercial marketing, supported by civil society, can support a protocol for adoption by the UN General Assembly, providing impetus for further legal and constitutional protections for children at national level.

Children and young people are full of energy, ideas, and hope for the future. They are also angry at the state of the world. Worldwide, school-children and young people are protesting about environmental threats from fossil fuel economies. We must find better ways to amplify their voices and skills for the planet's sustainable and healthy future. The SDGs require governments to place children at the very centre of their plans to address this crisis. This Commission makes positive and optimistic recommendations–but we have no time to lose, and no excuses if we fail. A new global movement for child and adolescent health is today an urgent necessity.

Introduction

Prompted by the end of the Millennium Development Goal era, with its focus on child survival, a Lancet Commission to place children's health and wellbeing at the centre of the Sustainable Development Goals (SDGs) was formed in 2018. The Commission was co-chaired by Helen Clark, former Prime Minister of New Zealand and former Administrator of the UN Development Programme, and Dr Awa Coll-Seck, Minister of State in Senegal. The Commission aimed to consider the ways in which governments, medical professionals, and society as a whole can accelerate progress on child health and wellbeing strategies in the context of the SDGs.

We can no longer consider child health and wellbeing the prerogative of health professionals. Immunisation, antibiotics, antenatal and delivery care, and good quality health systems are of course essential,[1] but we urgently need a broader plan to accelerate progress in areas previously neglected, such as early years development, adolescent health, and disability, and the development of a coherent narrative to guide our work across sectors. More immediately, we must respond to environmental and existential threats, which jeopardise the future for children on this planet. We require a holistic view of the child, defined here as a person aged 0–18 years old, whose wellbeing is at the centre of humanity.

"Our house is on fire"

Over the past 50 years we have seen dramatic improvements in survival, education, and nutrition for children worldwide. Economic development, concerted international action, and political commitment have brought about rapid change. In many ways, now is the best time for children to be alive,[2] but economic inequalities mean benefits are not shared by all, and all children face an uncertain future. Climate disruption is creating extreme risks from rising sea levels, extreme weather events, water and food insecurity, heat stress, emerging infectious diseases, and large-scale population migration.[3] Rising inequalities and environmental crises threaten political stability and risk international conflict over access to resources. By 2030, 2·3 billion people are projected to live in fragile or conflict-affected contexts.[4]

Children have little voice in the shape of their future. Decisions that will affect their lives are taken by parents, local leaders, governments, and global economic decision makers, and by the captains of global corporations with enormous resources and purely commercial interests. Environmental harm to children now and in the future is intimately linked to our economic structures and commercial activity. When youth climate activist Greta Thunberg spoke at the World Economic Summit in Davos, Switzerland, in January, 2019, she told delegates, "I want you to act as you would in a crisis. I want you to act as if our house is on fire. Because it is."

Childhood is the ideal time to intervene

Childhood is a special time of vulnerability but also of opportunity. Pregnant women and girls are vulnerable to biological and social risks that increase their susceptibility to disease, disability, and preventable mortality. Interventions during pregnancy, childbirth, and infancy can have a major effect on the health of both mother and child. A healthy mother is a good outcome in and of itself; care and nutrition for mothers before and during pregnancy contributes to the programming of a child's healthy growth and development throughout their life course. After birth, breastfeeding provides personalised medicine to the newborn—a potent tool for improving health, if we can overcome the poor support for breastfeeding mothers and regulate the inappropriate promotion of formula milk by a $70 billion industry.[5] Interventions in the newborn period and good newborn care can also prevent long-term disability.[6] We can do far more to support the 10% of children with developmental delays and disabilities, who require special care and attention; most of whom do not receive the care they need.[7] Providing such care will allow these children to participate fully and equally, a huge gain for society.

Evidence from longitudinal studies reports that the benefits of healthy childhood development extend to older ages: birth weight, infant growth, and peak physical and cognitive capacities in childhood are associated with or predictive of older adults' physical and cognitive capacities, muscle strength, bone mass, lens opacity, hearing capacity, skin thickness, and life expectancy.[8–10] A meta-analysis of 16 independent studies concluded that a 1 SD advantage in cognitive test score assessed within the first two decades of life is associated with a 24% lower risk of death over a follow-up period of 17–69 years.[11] Good nutrition in childhood is the basis for many such gains. Yet the so-called double burden of malnutrition means that overweight and obesity can coexist with undernourishment and micronutrient deficiencies within a single population. WHO describes the rapid rise in childhood obesity as "one of the most serious public health challenges of the 21st century."[12] The number of obese children and adolescents increased ten times from 11 million in 1975 to 124 million in 2016. In part, urbanisation has increased access to junk food and reduced access to play areas and safe exercise spaces. Our societies created these challenges—meaning it is within our power to reverse them.

The adolescent period (defined as children aged 10–18 years in this Commission) is another window of opportunity, given its critical developmental timing in terms of identity, agency, and vulnerability.[13] In adolescence, patterns can be laid for a lifetime of poor nutrition, reduced exercise, alcohol and tobacco use, mental ill health, and interpersonal violence. Worldwide 10–20% of children and adolescents experience mental disorders,[14] but early intervention in this age group is largely absent—a huge opportunity to improve wellbeing

throughout a person's lifespan. Adolescence presents an ideal time for conversations about nutrition, exercise, mental health, relationships, drug use—such as smoking, vaping, and alcohol consumption—domestic and gang violence, positive sexuality, and active and engaged political citizenship. Yet little research has been done on how to do so on a large scale.

Governance and voice

In the SDG era, country leadership requires a coherent national vision of child wellbeing, a necessary precursor to ensure aligned institutional frameworks and coordination mechanisms across ministries and sectors. Such a framing is already proposed by the UN Convention on the Rights of the Child (CRC), opened for signature in 1989 and ratified by all nations, except the USA. Yet so-called joined-up governance, which aims to coordinate and implement policies across government,[15] must emerge from local realities, to ensure communication across government departments, between a country's decision making centre and the most socially and politically isolated areas, and incorporate processes to ensure citizens (including children) participate in governmental decision making. Like the SDGs, strategies to improve child health and wellbeing cannot succeed unless they are truly multisectoral. The home, workplace, and places of learning are all opportunities for convergence of service delivery, but this will require significant changes in governance driven by strong and focused leadership.

Governance must also account for the fact that corporate power to reach individuals has never been greater. In our modern world, many multinational companies have larger financial capitalisations than medium-sized countries—with 69 of the 100 richest entities on the planet being corporations, not governments.[16] Additionally, the rapid spread of sophisticated digital and mobile communications means that children are exposed, as never before, to a torrent of commercial marketing pressures from corporate powers. The power of big business means government attempts to protect children from harmful commercial behaviour requires agile regulation, but this is often opposed by well-resourced lawyers and lobby groups. Commercial governance is essential to protect children from alcohol, tobacco, and insidious advertising which encourages formula feeding, junk-food diets, consumption of sugar-sweetened beverages, gambling, violent media and games, inappropriate sexual behaviour, and other risks.

The Commission

This Commission reports on urgent and actionable agendas for our children's future. First, we make the case for putting child wellbeing at the centre of SDG policies. Second, we describe what needs to be done: the package of entitlements that governments and other stakeholders should ensure each child receives, and the equity-focused investments and social mobilisation required to make it happen. Third, we describe how global, national, and subnational governance must be reconfigured to provide strong multisectoral solutions. Fourth, we address the enormous challenge of commercial regulation in keeping our children safe and healthy, and suggest new approaches to protect them. Fifth, we review how countries can build accountability through child-centred SDG measurements, and the immediate top-down and bottom-up action required to track progress. Finally, we offer 10 key recommendations to build a new global movement for the health and wellbeing of children and adolescents (panel 1). Although the scope and scale of our recommendations might seem daunting to rich governments of high-income countries (HICs), let alone those that struggle to provide their citizens with basic services, we believe positive change is possible at every level.

Placing children at the centre of SDG policies

Concern for future generations is already at the centre of the SDG endeavour. Here, we further theorise the concept of sustainability around children's health and wellbeing, and existing global frameworks, such as the Survive-Thrive-Transform framework of the Global Strategy for Women's, Children's and Adolescents' Health (2016–2030).[17] We also synthesise the evidence in favour of intervening in childhood to not only achieve child health goals, but also derive key benefits throughout the life course and for future generations. Finally, we set the stage by identifying key messages for stakeholders in all sectors, without whose collaboration child health goals cannot be met (panel 2).

Sustainability is for and about children

The threats to global health from disturbances in planetary health are profound and imminent.[3] More than 2 billion people, including half the world's poorest populations, live in countries where development outcomes are affected by political fragility and conflict, problems increasingly linked with climate change. In 2018, 1 billion people had moved or were on the move, with international migration increasing to 258 million people.[18] 22 million of these people were refugees, with 40 million people displaced by conflict, natural disasters, or climate change, including many children.[19] Even under best-case scenarios, these numbers will increase greatly as the face of the planet is remade by the effects of climate change.

In 2015, the world's governments adopted 17 SDGs, with 169 targets to achieve by 2030. The SDGs convey a dual vision: to protect our planet from a dangerous and uncertain future and to ensure that we deliver secure, fair, and healthy lives for future generations. Children are at the heart of this vision, with their own needs, rights, perspectives, and contributions. They are the bridge to the future, and they demand our commitment

Panel 1: **Recommendations for placing children at the centre of the Sustainable Development Goals (SDGs)**

- Heads of state should create a high-level mechanism or assign one overarching department to coordinate work with and for children across sectors, create an enabling environment to enact child-friendly policies, and assess the effect of all policies on children
- Heads of state and governments should create or designate a monitoring system to track budget allocations to child wellbeing, using this process to mobilise domestic resources, by means of fiscal instruments that benefit the poorest in society, for additional investment
- Government officials at the relevant ministry, national academics, and research institutions should develop strategies to improve data reporting for SDG indicators measuring child wellbeing, equity, and carbon emissions, using country information systems and citizen-led data and accountability
- Local government leaders should establish a cross-cutting team to mobilise action for child health and wellbeing, involving civil society, children themselves, and other stakeholders as appropriate
- UNICEF child-health ambassadors and other global children's advocates should mobilise governments and communities to adopt child-friendly wellbeing and sustainability policies, and advocate for rapid reductions in carbon emissions to preserve the planet for the next generation
- Leaders in children's health, rights, and sustainability should reframe their understanding of the SDGs as being for and about children, and the threat to their future from greenhouse gas emissions, mainly by high-income countries
- Children should be given high-level platforms to share their concerns and ideas and to claim their rights to a healthy future and planet
- Country leaders on child health and child rights should push for the adoption of new protocols by the UN Convention on the Rights of the Child to protect children from harmful commercial practices
- Country representatives to the UN should work together to create a simplified, effectively multisectoral UN architecture to reduce fragmentation and siloes, and to put action for children at the centre of the SDGs
- WHO and UNICEF leadership should meet with heads of other UN agencies to plan coordinated action to support countries to enact focused, effective policies to achieve the SDGs, and work with regional bodies to help countries to share progress and best practices

and accountability. Children are also the most vulnerable to the lifelong environmental effects caused by climate change arising from anthropogenic greenhouse gas emissions, and from industry-linked pollution of the air, water, and land.[20–22]

Fundamentally, the SDGs are about the legacy we bequeath to today's children. For that reason alone, children should be placed at the centre of the SDG endeavour. The SDGs are the agreed-upon global framework for working in the present to leave a legacy of a healthy, sustainable planet and future for our children; the UN Human Rights Council sees a clear link between the SDGs and the CRC, which is the world's most widely ratified human rights treaty. The case for putting children at the centre of the SDGs is based on their rights, sustainable economic development, a life course approach to wellbeing, and the notion of intergenerational justice and fairness. Furthermore, making children the human face of the SDGs helps us define progress towards sustainability.

In a world where social inequalities and anti-immigrant feeling are increasing and border walls are seen as a political solution, we need to build broader principles of inclusion, including intergenerational ones. The problems of the economy and environment are inherently linked as the root of conflict in our societies. Unjust economic policies have led to homelessness and hunger, even in the richest countries, as documented by the UN Rapporteur on extreme poverty and human rights on visits to the USA[23] and the United Kingdom.[24] Looking to the future, we emphasise the importance of humanitarian responses, safety from violence and displacement, and protection of children's and human rights in all contexts.

Panel 2: **Placing children at the centre of Sustainable Development Goals policies—key messages**

- Sustainability, and the Sustainable Development Goals, can be usefully conceptualised around action for the health and wellbeing of children
- The health of children, and their future, is intimately linked to the health of our planet
- Interventions to improve health and wellbeing during childhood have immediate, long-term, and intergenerational benefits, which compound synergistically
- The economic investment case for investing in children's health and education is irrefutable and is characterised by high benefit–cost ratios
- Within government, all sectors have a role to play in improving children's health and wellbeing

Children are speaking out about their world, and we share their concerns (panel 3). Children's concerns about their wellbeing focus on feelings of family togetherness, feeling safe, and enjoying healthy environments. These principles must guide us when building a world for this and the next generation of children. The consequences of not meeting our sustainability goals will fall upon children and young people—our most precious resource—and individual citizens who deserve health,

Panel 3: Children's wellbeing in their own words

We asked children aged 6–18 years to describe what made them feel happy and healthy in focus group discussions with indigenous Māori communities from rural New Zealand; disadvantaged urban neighbourhoods in Lebanon; relatively affluent communities from Ibadan, Nigeria; and very poor communities from La Plata, Argentina (appendix pp 1–2). In all settings, children cited key themes, such as family togetherness, safety from violence, clean environments, and access to culture and education, as most important for their happiness.

When asked about health and wellbeing, children cited their first priority as: "the things that will keep me happy and comfortable is that my parents love me and that we are complete in my family" (Nigeria), or "[being healthy is] playing with my whānau [extended family] and my mum and dad" (New Zealand). Children often linked their own happiness to the happiness of those around them, both within loving and caring families and in their broader neighbourhoods. "When other people are happy, we are happy," said a girl from Tyre, Lebanon. Children's joy in life was often expressed in simple pleasures: as one hearing-impaired child in Nigeria said, "It's fun to be a kid because you have opportunity to play."

Children were very sensitive to their environments, both within their homes (a "warm dry house" in New Zealand) and their local environment, which they sometimes described as marred by trash, noise, exhaust, pollution, or other contaminants. In Argentina, teenagers mentioned dogs and rats as threats to their health, and they were disturbed by garbage dumps. Children and youth often mentioned the desire to participate in cleaning up their local environments whether by clearing brush (Nigeria), cleaning up the beach (New Zealand), sweeping the roads (Lebanon), or generally "improving the country" (Argentina).

Children said their wellbeing was threatened by violence. In insecure environments, children frequently recounted being scared at witnessing violence, such as fights, shootings, or fatal car or motorcycle accidents. Drug use, absence of security, and prevalence of robberies was mentioned as an issue of community cohesion, as in Argentina: "If they know you, there is generally no violence against you. When people know each other, there is less violence." But in other cases, children spoke of being beaten or hit in their homes and said this was wrong: "[parents] should not be harsh on them; it is child abuse for small small children" (Nigeria). Often children worried about being bullied, sometimes for their religion, ethnicity, or nationality, or being sexually harassed.

Finally, children often cited a desire to attend school and learn about and participate in their culture. They said children should not have to work or marry: "Children should be in school, learning" (Nigeria). In Argentina, teenagers said schools gave them the information they needed to make the right choices in life and improved their mental health through art and music. Indigenous children from New Zealand also emphasised their connection to their culture ("Te Ao Māori"—the Maori world) and the importance of speaking their language and learning about traditions of song and storytelling. "It feels special when you're Māori," said one child.

See Online for appendix

wellbeing, and a planet capable of sustaining life into the future.

We take a life course-based approach, from preconception to adolescence, which makes the link to intergenerationality because the health and wellbeing of children is linked to that of their parents and other individuals making up their society, and their own future children and grandchildren. Children's specific factors of vulnerability, and protective factors across their life course are represented in the upper part (protective) and lower part (vulnerability) of our model (figure 1). The equity gap or gradient is represented by the distance between upper and lower curves, affected by the social and environmental determinants of health to the right of the gap arrow. While the equity gap is intergenerational in its mode of social reproduction, the smaller starting point in the early stages of life reflects the evidence that early childhood is a good window of opportunity to intervene and break the cycle of intergenerational poverty. Finally, the rights approach is shown by the upper curve, using a life course approach and incorporating the four foundational principles of the CRC. Thus, child wellbeing is anchored in rights and equity across their life course, with the aim of enhancing protective factors and mitigating vulnerability. The model also shows the inseparability of the agendas to promote women's and child's rights, health, and wellbeing, as put forth in the Global Strategy on Women's and Children's Health (2016–2030),[17] whose objectives and targets are aligned with the SDGs.

Intervening in childhood has lifelong, intergenerational benefits

"An ounce of prevention is better than a pound of cure," said Benjamin Franklin, and a rich body of theoretical and empirical literature describes how interventions in early childhood generate higher returns than remedial actions later in life. Early childhood, when brain plasticity and neurogenesis are intense, is a vital period for cognitive and psychosocial skill development.[25] Decades of developmental psychology research have reported the highly interactive process through which children develop the cognitive, social, and emotional capacities that are foundational for school achievement and adult economic productivity.[26] Investments and experiences during the early childhood period create the foundations for lifetime success.

Early investment should start before birth because the 9 months in utero is an essential period and conditions

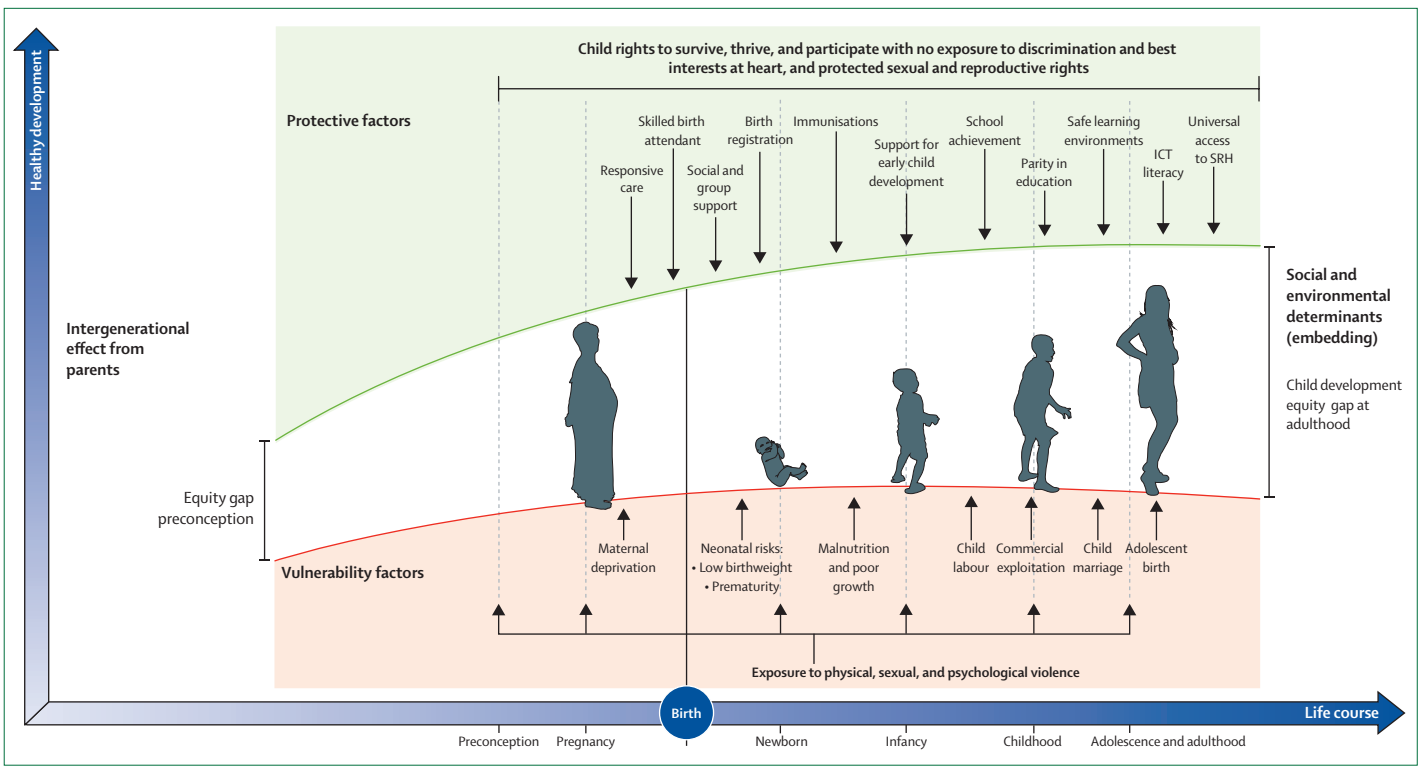

Figure 1: **Sustainable Development Goals measuring protective and risk factors for child wellbeing across the life course**
ICT=information communication technology. SRH=sexual and reproductive health.

during pregnancy shape the future trajectory of abilities and health.[27] Before pregnancy, women and adolescent girls should receive nutritional and counselling interventions to ensure they are healthy and equipped to make decisions about whether and when to become mothers. Maternal health interventions are critical to prevent, detect, and treat problems early during pregnancy and ensure women have access to high-quality care in case of complications. Food and iodine supplementation before or during pregnancy and antenatal corticosteroids for women at risk of preterm birth in HICs have beneficial effects on child development.[28,29] Smoking cessation during pregnancy, which can be supported by psychosocial programmes, also reduces low birthweight, and preterm births[30]—outcomes strongly related to improving early childhood development. Research has also shown the developmental origins of adult diseases like diabetes, heart attacks, and strokes.[31,32] Prenatal exposure to environmental contaminants is associated with epigenetic changes, such as DNA-methylation, linked to the development of diseases later in life.[33] For example, studies in Sweden on the radioactive fallout following the accident at the Chernobyl nuclear power plant, Pripyat, Ukraine, show that in-utero exposure affected educational attainment and income many years later.[34] Economists' work on fetal exposures has also suggested long-term economic effects, including reduced test scores and earnings.[35]

Fetal and early-life nutrition is also essential for long-term health, cognitive development, and economic outcomes.[36,37] Poor fetal growth or stunting in the first 2 years of life leads to irreversible damage, including reduced adult height, lower attained schooling, and lower adult income. Children who are undernourished in the first 2 years of life and who put on weight rapidly later in childhood or in adolescence are at high risk of obesity and later chronic diseases, such as diabetes, heart attack, and stroke.[37] Early-life nutritional interventions, such as the promotion of breastfeeding and iodine supplementation, consistently show benefit-cost ratios that exceed one.[38] Improving gender equality also has benefits for child nutrition, and is an independent predictor of child malnutrition and mortality in cross-country comparisons.[39]

Yet an estimated 250 million children younger than 5 years old in low and middle-income countries (LMICs) are at risk of not reaching their developmental potential.[40] At the same time, we know what children need for healthy development: nurturing and responsive care to promote their health, nutrition, security, safety, and opportunities for early learning.[41] Children with disabilities or an impairment of functioning require screening and early interventions so that they too can reach their full potential. Follow-up studies of children exposed to poverty, from a wide range of countries, show the beneficial effects of early childhood interventions for adult earnings, cognitive and educational achievement, health biomarkers,

reductions in violence, reduction of depressive symptoms and social inhibition, and growth (eg, increasing birthweight and head circumfrence) in the subsequent generation.[40]

In Jamaica, 2 years of psychosocial stimulation to growth-stunted toddlers increased earnings by 25% 20 years later, sufficient to catch up with individuals who were not stunted as children.[42] In the USA, the HighScope Perry Preschool programme had estimated annual social rates of return of 7–12% meaning that every dollar invested resulted in $7–12 benefit per person.[43,44] Much of the effects in adulthood come from changes in personality traits, such as academic motivation and aggressive behaviours, as opposed to cognitive improvements.[45] In making the economic case for early childhood interventions, wider benefits to society have been reported, including reductions in crime.[46] The benefits are personal, societal, and intergenerational: a recent analysis of wide-scale school construction in Indonesia between 1973 and 1979 found that increased parental education benefited children through increased household income, better living standards and housing, and paying higher taxes.[47] An increasing amount of evidence shows the synergistic benefits of interventions in early years being followed by later interventions in middle childhood and adolescence, particularly in populations who are exposed to high developmental risk.[48]

Life course investment frameworks highlight the so-called dynamic complementarities of human capability and the role of self-productivity.[49] Capabilities learnt early in life provide the foundation for increasing the productivity of investments later in life. In other words, investments at different stages of life are synergistic. Self-productivity refers to the idea that capabilities are self-reinforcing, for example better health promotes learning. Together, dynamic complementarity and self-productivity produce multiplier effects through which capabilities beget capabilities. Such frameworks provide a strong rationale to invest in early childhood, and to keep investing into middle childhood and adolescence.

Investments in children's health and education are highly cost-effective

Health is of value in its own right. People place great value on living longer, healthier lives. Parents prioritise the health of their children. In surveys around the world, health is typically found to be one of the most important determinants of happiness and life satisfaction.[50]

An extensive body of evidence reports on the cost-effectiveness of health interventions for children.[48,49] Scaling up integrated maternal, newborn, and child health packages to 90% coverage in 75 countries in which more than 95% of the world's maternal and child deaths occur could avert 849 000 stillbirths, 1 498 000 neonatal deaths, and 1 515 000 additional child deaths.[51] Increasing access to such packages is essential because complications from prematurity, intrapartum-related events, and infectious diseases—such as pneumonia—remain the leading causes of death in children younger than 5 years old.[53] Intervening early costs less than attempts to compensate for early deficits with remedial interventions at older ages.[41] An analysis, published in 2017, suggests that the cost of inaction for not improving child development through universal preschool and home visits, and reducing stunting, is substantial and could reach more than 10% of gross domestic product (GDP).[54]

Global investment cases that estimate the benefit-cost ratio of investing in health and other sectors are summarised in figure 2. Translating health gains into monetary values is challenging from an ethical and a methodological perspective, and can be done in multiple ways.[55] Although no shared consensus exists, estimates value a year of life in LMICs in the range of 1·5–2·3-times GDP per capita.[56,57] Using the more conservative value of 1·5, analyses suggest that the economic (eg, productivity) and social benefits (eg, health) of expanding a set of integrated interventions for women's and children's health are 7·2-times more than the costs in low-income countries (LICs) and 11·3-times greater in lower-middle income countries.[58] Valuing a year of life at 2·3-times GDP per capita, The *Lancet* Commission on investing in health produced higher benefit-cost ratios for a similar set of health interventions.[56]

Studies into global investment for education, founded on a wealth of evidence,[59] show that each $1 invested in education will generate an additional $5·2 of benefits through increased earnings in LICs and $2·5 of benefits in lower-middle income countries (figure 2). These benefit-cost ratios almost double when the health benefits—reduced adult and child mortality—of improving education are taken into account. Incorporating the monetary value of reductions in mortality means each $1 invested in education will generate an additional $9·9 of benefits in LICs and $3·7 of benefits in lower-middle income countries. These benefits could be an underestimate, given that studies show a range of other benefits of high-quality education on sexual and reproductive health, mental health, reduced risk of non-communicable diseases later in life, reduced tobacco smoking and drug use, and fewer incidents of violence.[60]

To thrive at school, children must be healthy and well nourished. A powerful economic argument for targeting the health and development of school-age children is that it promotes learning during their only opportunity for education.[61] Ill health and poor nutritional status impair learning. For example, malaria and worm infections reduce school attendance and are a leading cause of anaemia, which can negatively affect cognition and sustained attention.[62,63] Health interventions to prevent or treat infectious disease can have a positive effect on learning and in turn generate long-term economic benefits in the form of higher earnings.[62,64–67] These synergies suggest that health and education are two sides of the same coin. A global investment case for adolescents[68]

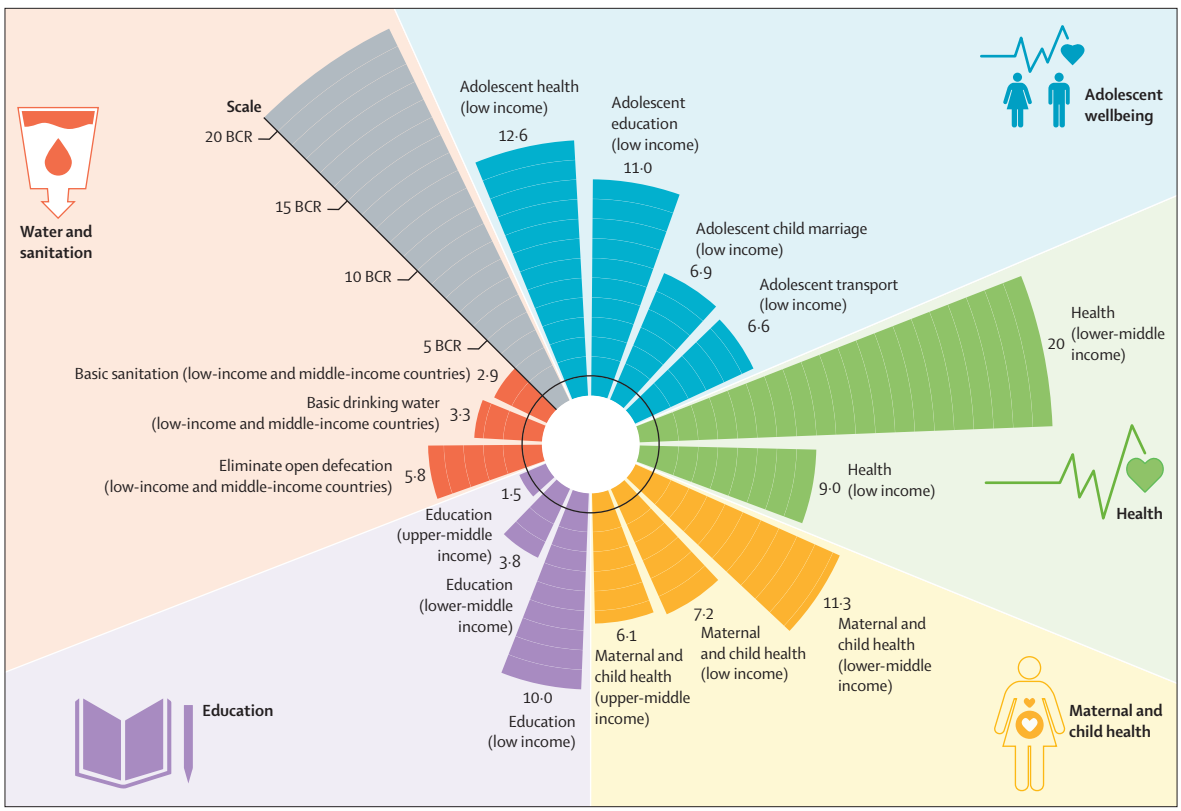

Figure 2: **Benefit-cost ratios: returns on every US dollar invested**
BCR=benefit-cost ratio. LMIC=low and middle-income countries. MCH=maternal and child health. A benefit-cost ratio of one (grey circle) indicates costs and benefits are the same. A ratio of more than one indicates that the benefits are more than the costs. Each concentric ring equals a BCR of 10. The majority of countries excluded are high-income countries with some exceptions. The figure shows high returns to investment in children's health and wellbeing across a variety of domains. BCR is calculated by dividing the monetary benefit of an intervention by the monetary cost of implmenting it.

shows that investing in strategies to reduce child marriage and road accidents will also generate benefits that far exceed costs (figure 2). Although no analogous benefit-cost ratio calculations exist outside the health and education sectors, interventions in all sectors are widely understood to be investments in current and future societal outcomes, rather than just spending.

All sectors are responsible for children's wellbeing

Sectors beyond health and education can, and must, work to improve the health and educational attainment of children, to capture valued societal and economic benefits. The socioecologic environment in which children live can be seen as a series of concentric circles.[69] At the centre is the home, surrounded by its immediate environs, locality, and wider urban or rural area. Each of these circles balances opportunity with exposure and constraint. In the home, potentially harmful exposures include indoor air pollution, tainted water and inadequate sanitation, overcrowding, excessive cold or heat, damp and mould, domestic hazards from accident or violence, electricity, burns, noise, fire, flood, earthquake, environmental toxins, and hazardous location (eg, close to water bodies, dumping grounds, railway tracks, or roads). Children might also be exposed to alcohol use and abuse, second-hand tobacco smoke, and unhealthy diets, with links to food policy and regulatory schemes upon which families have little direct influence.

Good housing is essential. The rush to urbanisation has created a planet of slums. Informal settlements, in which approximately 40% of the world's children currently live, intensify many of the previously mentioned threats through a combination of substandard housing or illegal and inadequate building structures. Residents face overcrowding and high density, unhealthy living conditions and hazardous location, poor access to basic services, poverty and social exclusion, and insecurity of tenure.[70] Although we have too few locally disaggregated data,[71] we require no more evidence that these exposures and constraints have harmful effects on child health. Furthermore, the common division of household labour means that the greatest burden of indoor air pollution from burning of biomass fuels is borne by women and children.[72] Meanwhile, access to clean water and adequate sanitation is rare in such settings, despite being one of the most effective public health interventions a society can provide to improve health and wellbeing.

Harmful exposures related to the environment outside the home include air pollution, vehicular and pedestrian accidents, crime and violence, and urban heat islands (created by heat-retaining land surfaces). Opportunity and constraint centre on shops, schools, and other services, such as health care, transport, exercise, and green space. There is good evidence for associations between exposure to air pollution and intrauterine growth restriction and poor childhood respiratory health.[72–74] In terms of constraint, important concerns for child health include neuropsychological development, the food environment, insufficient active transport and opportunities for exercise, and traffic accidents. One area that merits special attention is road safety because road injury is the leading cause of death for children and young people aged 5–29 years.[75] Interventions to improve road safety are simple and relatively uncontroversial and include speed restrictions, mandating the use of seat belts and helmets, and strong penalties for driving under the influence of drugs and alcohol, but enforcement remains a challenge.

Only a small amount of research on the effects of the surrounding neighbourhood on early child development has been done.[76,77] Neighbourhoods with amenities, such as libraries, schools, and recreation centres, are positively associated with child physical health, social competence, and wellbeing, and negatively with vulnerability to developmental delay.[78] UNICEF frames the idea of a child-friendly city within the UN CRC.[79] Urban planners have been attempting to modify the physical environment to increase exercise through walkability, leisure opportunities, and active transport.[80] Intuitively, and with some evidence, children's physical activity increases with access to safe roads, parks, and recreation areas, and decreases with traffic and crime exposure.[81,82] The idea of playability as a stimulus to exercise is receiving interest.[83] Children have a right to play,[84] and require spaces to do so. Neighbourhoods that are protected from traffic and have green spaces are more conducive to outdoor play and physical activity.[78] Some evidence shows a positive effect of green space on cognitive development and mental health,[85,86] and that green space is associated with improved obesity-related health indicators.[87] Given concerns about non-communicable diseases and obesogenic environments, modifying the food environment and increasing exercise are urgent, but the evidence base for action is small.[88]

Child health intersects inescapably with the planetary health and non-communicable disease agendas in the local community. Street connectivity, appropriate housing density, and walkability are win-win aspirations for health and the environment, but direct links with child health have been difficult to show.[74] People want environments safe from air and toxic pollution, road traffic accidents, crime and violence, places that offer social interaction, walkability and playability, and a range of services and amenities that have benefits for both health and environment. For example, traffic calming and the existence of playgrounds are associated with both more walking and less pedestrian injury.[89]

For both planetary sustainability and child wellbeing, clean energy remains a huge development challenge. In 2016, around 3 billion people (1·9 billion in developing countries in Asia and 850 million in sub-Saharan Africa) were without clean cooking fuel or technologies, creating harmful indoor air pollution estimated to cause 3·8 million deaths per year.[3,90] The number of people without access to electricity fell from 1·7 billion in 2000 to 1·1 billion in 2016; however, most of the newly accessed electricity was generated with fossil fuels, a key challenge for decarbonised energy systems. Electricity growth in China and India is largely driven by coal-generated power stations; coal remains the main fuel used for electricity production worldwide, at 37% of the total.[91] A shift of investment towards clean energy technologies is happening, with accelerating growth in new low-carbon power generation, but overall global energy-sector carbon emissions remain largely unchanged.[3]

Energy and the industrial sector are linked inextricably with air pollution. Exposure to polluted air prenatally and during early postnatal life is associated with an increased risk of acute respiratory diseases in childhood, with considerable morbidity and mortality.[92,93] Furthermore, air pollution exposure impairs lung growth and reduces lung function;[92] increases the risk of cardiovascular disease,[94] obesity,[95] type 2 diabetes, and metabolic syndrome;[96] slows brain maturation; and impairs growth in cognitive function in schoolchildren.[97,98] Emerging evidence also suggests statistically significant effects of air pollution on intelligence quotient (IQ);[99] one study reports a four-point drop in IQ by the age of 5-years in a sample of children exposed to polluted air in utero.[100] Reducing air pollution can quickly improve children's health: for example, effective reduction of air pollutants in Southern California through legislation resulted in increased lung function growth and reduced respiratory symptoms in children.[101,102] However, regulation is complicated by the fact that air pollution can be a transnational issue (eg, spill-over of pollution between China and South Korea was associated with increased mortality from respiratory and cardiovascular diseases in South Koreans, including children younger than 5 years old).[103] Pollution control would improve child wellbeing, with children living in LMICs having the most to gain.

Summary

We have provided a rationale for placing children at the very centre of the SDGs and reviewed medical, public health, and economic arguments in favour of investing early in children's health and wellbeing, across all sectors. We now turn to the issue of children's entitlements, and how to deliver them, as a way of operationalising a new global movement for children's health and wellbeing.

How to ensure that children receive their entitlements?

Putting children at the centre of the SDG agenda will enhance our drive for sustainable development. Here, we define the actions needed to achieve this agenda by laying out a set of entitlements for children and detail the responsibility of families, communities, and governments, required to deliver them (panel 4).

What entitlements and rights should children expect?

Placing the SDGs in the service of children involves building on a legacy of commitments to human rights, beginning with the Universal Declaration on Human Rights, adopted by the UN General Assembly more than 70 years ago, that outline the inalienable entitlements of all people, at all times and in all places, as a foundation for freedom, justice, and peace in the world. The CRC, which recognises and affirms children's rights specifically, turned 30 years old in November, 2019. In many ways the CRC was a precursor of the SDG framework.[104] The CRC is comprehensive, and not only states children's rights to preventive, promotive, and curative health care, "… but also to a right to grow and develop to their full potential".[105] The CRC further declares that all children (aged 0–18 years) are entitled to survival, protection, development, and participation.

Every UN member state (except for the USA) is party to the CRC, which provides the foundation for the rights of children. As a convention it is legally binding; as a result, it goes beyond the voluntary SDG framework. While individual countries have turned the CRC into law and aim to report once every five years on the fulfilment of the CRC to the UN Committee on the Rights of the Child (Austria, Australia, Belarus, El Salvador, Mozambique, Rwanda, Tonga, Tuvalu, and Sri Lanka reported in 2018, with 17 other countries reporting in 2017),[106] the CRC has yet to be widely used to advocate for children in the context of the SDGs. Violations of children's rights are common across many domains, such as poverty; inadequate nutrition; violence and war; gender bias and discrimination against sexual minorities; poor access to clean water, shelter, education, and health services; and climate degradation and unsustainable use of planetary resources.

The Convention is a legal document that commits governments to fulfil the rights of all children living within their country. We extrapolate that an inclusive set of entitlements for children in the SDG era can be articulated and monitored, expanding the CRC's accountability framework to provide regular reporting of their fulfilment. The general comments to the CRC, considered authoritative interpretations of the rights articulated therein, provide the basis for this package of entitlements. The entitlements are organised across five over-arching rights and presented according to a continuum of children's ages (many of the rights apply to all children aged 0–18 years; figure 3). Because the entitlements are based on rights, granting them is not optional, although countries might use different policies or interventions to deliver them. Of note, one of the key prerequisites for these entitlements to be delivered is birth registration, yet a quarter of children younger than 5 years old worldwide are not registered.[107]

In many documents, including this Commission, children are defined by age group and their absolute or relative dependency on adult care, protection, and advocacy. However, in the sense that we all have (or have had) parents or caretakers, we are all children and exist in a set of relationships with corresponding rights and responsibilities. First, across families through time and generations—from ancestors, grandparents, parents and to future generations; second, within communities across geography and social place—where our families are from, our homelands, and our ways of life; third, in relation to local and national governments—where key services are planned, budgeted for, and coordinated, and bodies are empowered to guarantee rights, and where nations work together on transnational issues; finally, embedded within our environment—from the planet, to sources of food, water, and air, and places where we lay the dead to rest.

These dynamic relationships have parallels in how rights and responsibilities are balanced across society in order to respond to the entitlements of us all as children. We previously discussed our responsibility to protect and preserve our planet for children's present and future wellbeing. We now examine how children, families, communities, and governments, can help to fulfil children's entitlements under the CRC.

Panel 4: Ensuring children receive their entitlements—key messages

- Children's rights and entitlements are comprehensively defined by international treaties, including the Convention on the Rights of the Child, which are widely ratified
- Children are key stakeholders in an interconnected web of rights and responsibilities, which binds humanity together and to our planet in a shared endeavour of mutual care
- Children have a right to claim their entitlements and participate in discussions about how to deliver them
- Families can best provide nurturing care for children when the rights of their mothers and other caregivers are realised
- Communities are powerful forces for positive change in children's lives, especially when society allows for equitable participation
- Governments must do much more in terms of public financing of services, effective delivery, and equitable social protection, adequately financed to meet the Sustainable Development Goals

The pre-eminent role of children and families

Children themselves, as well as their families, must be at the centre of efforts to act collectively to ensure that

by 18 years of age they are optimally healthy, educated, engaged in productive citizenship, and act as stewards of the Earth. Families are the immediate environments in which children are born, grow, play, learn, and contribute.

Involving children's voices in policies and programmes

As children develop, they ideally increase their "substantive freedom… to achieve valuable functionings"[108] in society. Recognition is growing that promoting meaningful participation of children contributes to improved social cohesion, more egalitarian communities, and helps adolescents make a better informed, healthier, and more empowered transition into adulthood.[13] Furthermore the CRC stipulates children's right to be involved in decisions and actions that affect them, to be able to express their views, which are then duly recognised by adults. The UN affirms that only by engaging

Be protected	Be educated	Be healthy	Be treated fairly	Be heard
• Adequate standard of living • Safe, supportive, and nurturing family • Safe leisure and play facilities • Violence free home • Regulated media and protection from inappropriate and offensive material • Safeguarded from abuse and neglect, and alternative, affectionate care provided (if required) • Free from violence and exploitation (physical, mental, and neglect) • Free from harmful and exploitative work, including sexual exploitation • Minimum age of criminal responsibility at 14 years old • Safe and adequate housing • Violence free school and community • No death penalty or life imprisonment without parole • Regulation of online and recreational material and age classification of media, broadcasting, and films • Online safety information regarding cyber-bullying, grooming, trafficking, and sexual abuse and exploitation, and information on where to access help • Regulation of fast foods marketing • Protection, care, and proper treatment, including guardian and legal representation, of unaccompanied and separated children • Unaccompanied and separated migrant or refugee children not to be returned to a country with a substantial risk of harm • Protection from economic and sexual exploitation • State should attempt to preserve the family unit in the case of child protection systems, including in the context of migration • Controlling of firearms • Restricted access to alcohol and drugs and regulation of advertising • Protection from harmful traditional practices and violence • Laws and standards relating to business and labour, employment, health and safety, environment, taxation, and anticorruption • No immigration detention • Legal minimum age of consent, regardless of gender; not specified for sexual and medical treatment consent; to be a minimum of 18 years for marriage, armed forces recruitment, and alcohol and drug use • Protection and standards for children of working age in businesses • Protection from armed forces and gang recruitment	• Free primary education • High-quality and safe primary schools • Specific early childhood education for children with disabilities • Child-centred and child-friendly education • Inclusive education and schools that are physically and culturally accessible • Education about respect for natural environment and sustainable development • Schools that are free from and that challenge discrimination • Education about and challenging racism • Human rights education • Promotion of values of human rights • Life-skills education promoting healthy behaviour, including personal hygiene, stress management, nutrition, and self-care • Community-based education challenging gender roles and stereotypes and harmful practices • Schools with well functioning and safe facilities • Time and space for age-specific and inclusive play and creativity • Time with peers and social activities • Time for rest and leisure • Access to digital media and the internet, including online safety education and legislation and laws to tackle online abuse • High-quality and accessible secondary schools • Vocational guidance and information • Drug, alcohol, and substance use education • Sexual health education • HIV/AIDs education and information • Road safety and driving education	• Parenting education and counselling services • Prenatal and postnatal health care • New born care • HIV/AIDS counselling, testing, and treatment for mothers and babies • Exclusive breastfeeding for children younger than 6 months old, and alongside complementary foods until 2 years, except in cases of HIV-infected mothers where replacement feeding is recommended if feasible • Immunisation, antibiotics, and antiviral drugs • Child-care services, maternity protection and facilities • High standard of health care • High-quality and accessible primary, secondary, and tertiary health care • Early detection of disabilities, intervention, treatment and rehabilitation, and physical aids • Clean drinking water • Good nutrition • Adequate sanitation • Specialist health care for children affected by substance abuse (eg, mothers affected by alcohol or drug substance abuse and risk of early initiation to substance abuse) • Information and advice on personal wellbeing and physical and mental health, both in and out of school, through the media and youth, religious, and community groups • Mental health services, treatment, and rehabilitation • No age limit on confidential counselling and advice without parental consent, regarding the child's safety or wellbeing (distinct from giving medical consent) • Specific health information, guidance, and counselling, including for children with disabilities and gender specific • Sexual and reproductive health information and services, including contraception and safe abortion • Affordable, accessible, voluntary, and confidential HIV/AIDS prevention, care, treatment, and support • HIV/AIDS education and information • Specific HIV/AIDS services and information for vulnerable and discriminated against groups • Human papillomavirus vaccinations for girls • Confidential HIV testing and counselling services, particularly for vulnerable and marginalised groups, including girls and LGBT adolescents • Sexual and reproductive health information and services, including contraception, family planning, and safe abortion services • Right to privacy and confidentiality regarding medical information, advice, and counselling • To give consent for medical treatment, as well as parents or guardians, and, if of sufficient maturity, give sole consent without parental consent (age not specified)	• Access to health care, education, protection, and services without birth registration • Specific measures to ensure birth registration for vulnerable and marginalised groups, including children with disabilities, indigenous children, and children in street situations • Support for parents of children with disabilities • Free from discrimination, including children with disabilities, indigenous children, LGBT children, migrant children, children in the juvenile justice system, and HIV/AIDS affected children • Access to education for girls • Educational and economic opportunities for girls • Education free from discrimination and barriers for marginalised groups • Equal right to education, health care, and standard of living for marginalised children, including unaccompanied and separated children, migrant and refugee children, children in street situations, and children with disabilities • Vulnerabilities taken into account when looking at best interest • Separate juvenile justice system focusing on rehabilitation and restorative justice, with education, medical care, leisure time, and contact with family and community • Specific focus on protection for marginalised or vulnerable groups from economic and sexual exploitation and violence, including HIV/AIDS affected children, children in street situations, children with disabilities, and migrant children • Special measures for groups who are marginalised or hard to reach in order to realise their rights • Specific measures for those with intersecting and multiple vulnerabilities • Conservation, development and promotion of cultural traditions for minority, refugee, and indigenous groups, including names, families, and language • Free from negative stereotypes about adolescence • Free to express sexuality and gender identity • Free to practise religion • Support for adolescents in care, including reviews of their situations and support for education, and help for leaving care in gaining employment, housing, and psychological support • Culturally sensitive and appropriate services for indigenous children, relating to health, education, nutrition, recreational sports, social services, housing, sanitation, and juvenile justice • Support for adolescent mothers, fathers, and carers, including help to stay in education • Treated equally before the law, including vulnerable and discriminated against groups • Children younger than 18 years to be treated in accordance with the rules of juvenile justice • Services and support for adolescents with disabilities, minority and indigenous adolescents • Removal of criminal record at 18 years of age	• Have a name and nationality • Birth registration • Responsive parenting • Preserve identity • Free late birth certificates and civil registration • Feedback and input on education • Sufficient and effective ways to report abuse or violence • Express views freely and be listened to in schools and by families and the community • Know own rights • Express views in any decisions affecting them • Child-friendly, age-sensitive, safe, and voluntary ways to express views in decision making • Access to sensitive advice, advocacy and complaints procedures relating to corporal punishment, disability discrimination, juvenile justice, violation of rights by businesses and migration • To be heard and effectively participate throughout the process of juvenile justice • Involvement in decision making, policies, programmes, and procedures, relating to HIV/AIDS policies, disabilities, health provisions, harmful practices and gender discrimination, indigenous children, children in street situations, immigration and asylum process, education, health, economy, environment, and care • Adolescents express views on matters that concern them and safe and accessible complaints procedures

Figure 3: **Summary of child entitlements as laid out in the General Comments to the Convention on the Rights of the Child**

***Panel 5:* Case study: U-Report**

U-Report is a free global platform open to individuals of any age. As of 2019, 28% of U-reporters worldwide are under the age of 20 years and 39% are between 20 and 24 years; 44% of all reporters are female.

U-Report aims to encourage community participation, especially by youth, in a wide range of issues including health, education, water, sanitation and hygiene, youth unemployment, and HIV/AIDS and disease outbreaks through mobile technology and social media. Started through UNICEF funding in 2011 in Uganda, U-Report draws on the opportunity provided by widespread use of mobile technology to enable youth to voice their opinions.

U-Report uses messenger polls and alerts sent via direct message combined with real-time responses that are mapped on a website. Responses can be disaggregated by region, gender, and age group enabling policy makers to have insights into the needs and opinions of specific groups. Cross-country polls have been used to gather data on issues affecting youth across all participating countries, such as school bullying and universal health coverage.

In 2019, 50 mostly low-income and middle-income countries have U-report programmes worldwide, with almost 6 million subscribers. The UNICEF team analyses and interprets the responses to messenger polls and shares the results with national policy makers and on the country U-Report websites; following which action can be taken.

In Uganda, where the initiative was launched, every member of parliament has signed up for U-Report and district health managers have used it to strengthen immunisation campaigns and use the programme as an early warning system for health system challenges, such as drug shortages. In Indonesia, through U-Report, young girls were able to share their opinions about child marriage and a delegation of selected young U-reporters convened a 1-day meeting at the Ministry of Women's Empowerment and Child Protection, which resulted in nine recommendations on child marriage prevention. A similar process was undertaken in El Salvador where U-Report was used to bring the opinions of children on child marriage to the legislative assembly where a prohibition of child marriage was called for. In Tunisia, U-Report has been used to gather views from youth on rights to education. In Liberia, which has the fourth highest participation rate of U-reporters globally, the government has used the platform to raise awareness around prevention of transactional sex among school girls (so-called sex for grades). In conflict-affected areas of the Ukraine, U-Report launched the U-ambassadors peer-to-peer initiative, in which U-Report was used to monitor water, sanitation, and hygiene; education and humanitarian programmes; and to provide online counselling on safe migration.

The U-Report initiative could be harnessed as a mechanism for community monitoring of certain Sustainable Development Goal indicators and the data from polls could be an important contributor to country monitoring processes.

For more on **U-Report** see https://ureport.in

and working with children and youth will the international community be able to achieve peace, security, justice, climate resilience, and sustainable development for all. Recently, youth activists in the school strike for climate movement have made forceful arguments to lower the voting age to 16 years, to protect children's right to have a say in decisions that affect their future on the planet.[109]

Engagement with children can be consultative, collaborative, or adolescent led, depending on the specific context and purpose. In policy formulation, if the aim is to reach out to as many young people as possible, a consultative approach might be best, potentially using digital tools such as U-Report, a free global social media platform used in more than 50 countries (panel 5). UNICEF made use of U-Report to gather inputs from more than 385 000 young people before the Global Conference on Primary Health Care, held in Astana, Kazakhstan, Oct 25–26, 2018, to feed into a 1-day preparatory workshop attended by more than 100 young participants. However, consultative processes do not always result in children's voices being heard: in Uganda, local authorities only engaged a small number of children despite the programme being a national child wellbeing scheme, resulting in a deprioritisation of their needs.[110] Among the challenges for effective engagement are adultism, the notion that adults always know better than children; a reluctance of overburdened local authorities to take on additional duties of listening to children; tokenistic child participation; exclusion of the most marginalised children; and weak adult facilitators.[111,112]

Collaborative and adolescent-led approaches have had powerful positive effects. Adolescent-led initiatives, such as Greta Thunberg's school strikes for climate movement mobilised an estimated 1·5 million students in more than 2000 cities worldwide in March, 2019, showing that traditional models of incorporating children's voices into environmental and economic policy have not been successful, and that social media platforms present catalytic opportunities to harness young people's engagement. In 2019, there are 1·2 billion adolescents in the world (defined by WHO as persons aged 10–19 years), of whom nearly 90% live in LMICs.[113] Adolescents are better connected than ever before, attend school more than in previous generations, and are well placed to drive progress on sustainability.

Adolescents might require adults to provide the scaffolding for engagement, including access to safe

spaces and a credible audience that they can influence.[114] Certainly, investments are required to address social norms, implement laws, and adopt policies that enable adolescent rights and create sustainable opportunities for participation. When these are in place, adolescent-led initiatives can drive progress on local concerns, such as the movement of girls in Argentina to claim their sexual and reproductive rights (including the right to abortion); adolescent-led protests concerning road traffic safety in Bangladesh; the student movement in Chile that led to a more equitable education system; and the social movement for better gun control in the USA following the Parkland, FL, shootings. Equally, grassroots youth movements can be encouraged to take the initiative and engage politically in the context of their rights and responsibilities as citizens.

Worldwide, documentation of children's own experiences of their day-to-day lives through narratives has been largely absent from SDG monitoring processes. Focused, smaller-scale research can provide valuable insights into the status of children's wellbeing in diverse contexts, particularly for younger children. Since 2009, the Children's Worlds Study has obtained comparative multinational data on children's understanding of wellbeing. The surveys collected representative data (from up to 90 000 children from 24 countries) on children's lives and daily activities, their time use, and their own perceptions and evaluations of their wellbeing.[117] Results from the second survey wave found that children felt most satisfied with their family life and friends, less satisfied with their local environment and life as a student, with the lowest amounts of satisfaction relating to their own future, especially in LMICs, such as Ethiopia, Nepal, and South Africa.

Innovative methods to understand children's perceptions of their environments include crowd-sourcing via social media, photovoice, and community mapping. They can garner children's views on the policies that affect them and integrate their views into explicit policy and monitoring frameworks. For example, a study from South Africa found that children from poorer communities were more constricted in their mobility and unable to access safe natural spaces compared with children from wealthier communities. The authors recommended that town planning processes include children as key contributors using participatory frameworks, such as UNESCO's Growing up in Cities model.[116] Another promising model of a participatory system for child rights accountability internationally is Global Child Rights Dialogue, an international consultation project that aims to seek children's input on the attribution of their rights as articulated under the CRC, in 40 countries around the world.[117]

Families' rights and responsibilities in nurturing their children

The realisation of children's entitlements depends on families. Young children require a stable environment created by parents and other caregivers to ensure good health and nutrition, protection from threats, opportunities for early learning, and love and emotional support.

Beginning with the maternal-infant dyad, the child's biological and developmental trajectory is ideally set in the context of nurturing relationships. The rights, freedoms, and entitlements of children can only be advanced when the entitlements of their mothers and care givers are realised. Moves to promote gender equality will improve nurturing care in the early years of life. A study covering 116 LMICs from 1970 to 2012 explored the relationship between two readily available proxies of women's control over their lives: the number of girls enrolled in secondary education and the ratio of female to male life expectancy.[118] Improvement in these two indicators was associated with 32% of the decline in stunting, a common proxy for child development, over the 42 year period for these countries. Within this broader understanding of the place of families in raising children, we consider the diversity of families and their changing social contexts, before considering key power relations, barriers, and enablers that families face in raising children in the SDG era.

Considerable diversity exists in family composition. A child could live with a single parent, two married or cohabiting parents (of any sex or gender), a grandparent, foster family, adoptive parent, or another relative or guardian. A child might live with siblings in a nuclear, joint, polygamous, extended, or blended household whose members are at home or elsewhere. Some children are orphaned and do not live with their biological parents. In 2018, worldwide, there were 140 million orphans (defined as any person under the age of 18 years who has lost one or both of their parents due to death from any cause).[119] Double orphans have lost both parents and make up 15·1 million of those children. Orphans often lack the protective buffer that familial structures ideally provide. Other children might live with disabled parents or caregivers, or be disabled themselves, and do not have access to expert and peer support for families and caregivers, to which they are entitled. According to data from the Social Trends Institute's World Family Map, children in sub-Saharan Africa, the Americas, and western Europe are less likely to live with both parents than children in Asia, the Middle East, Oceania, and eastern Europe (figure 4).[120] With the exception of the Middle East, the proportion of births occurring outside marriage varies widely. Children around the world not infrequently become parents themselves, with 16 million girls aged 15–19 years and 2·5 million girls younger than 16 years old giving birth each year in LMICs.[121]

In addition to regional differences, family structures are changing, linked as they are with demographic trends, and influenced by social, political, and environmental variation. Worldwide, life expectancy and the age at which women have their first child are rising, and fertility rates are falling. Economic migration and urbanisation disrupt

traditional family structures, whether these are nuclear families in some contexts or extended families in other settings. Economic opportunities often take parents away from their children, even when their decision to leave is motivated by a desire to advance their children's welfare and opportunities, complicating understandings of family wellbeing. As industrialisation and urbanisation accelerate in many parts of the world, hundreds of millions of children are left behind by their parents seeking work, and they face increased risk of mental health problems and poor nutrition, with no evidence of any health benefit.[122]

In HICs, the already substantial proportion of single-parent families is expected to continue to rise, to up to 27-40% of households in the USA, Australia, Austria, Japan, and New Zealand by 2025–30.[123] Women who are divorced or separated and single-parent families are more likely to live in poverty, which has implications for the social determinants of health. Furthermore, in sub-Saharan Africa and central and South America families are more likely to have a head of household without secondary education compared with other parts of the world, and in sub-Saharan Africa the head of household is less likely to be employed (figure 4).

Meeting basic needs remains a challenge for many families living in deleterious social, political, and economic conditions. Many families are unable to ensure their children breathe clean air or have sufficient good-quality food and water, or live in a sanitary environment. Despite these odds, many are still able to meet their children's needs for love, belonging, respect, confidence, and self-esteem. Recognising such resilience and the ability of families to support and realise their children's rights and entitlements must also be matched by government policies to address challenges posed by sociopolitical, economic, and environmental threats. Thus policy change remains a powerful way of shaping a progressive society that supports healthy growth, development, and equality. For example, improving girls' completion of quality schooling, safe transportation options for girls and women, productive labour force participation by women, and paternity leave policies for men creates enabling environments for a more gender-equitable society.[124]

Families can also be the locus of violence in a child's life, in part because of structural issues, such as discrimination and poverty, with consequences across the lifespan of the child and for society. This is particularly the case for girls and young women, as well as children who have non-conforming gender identities and sexual orientations. More than 1 billion children—half of all children—are exposed to violence every year,[125] including about six in ten children worldwide who are subjected to violent discipline by their caregivers on a regular basis.[126] The enduring effect of violence against children is well known, including increases in the risk of injury, mental health problems, sexually transmitted infections and reproductive health problems, and non-communicable diseases—including cardiovascular disease, cancer, chronic lung disease, and diabetes.[127]

Violence against children also begets further violence: high proportions of incarcerated people experienced violence as victims before becoming perpetrators, representing costs to society as well as to children themselves. A cross-sectional study of more than 36 000 US men and women suggested that nearly half of antisocial behaviours in adults could be accounted for by harsh physical punishment or maltreatment when they were children.[128] Society has a responsibility to protect children from violence within families, but worldwide government intervention into intimate family situations for child maltreatment falls heaviest on marginalised populations, including indigenous families, and racial and sexual minorities. Further, domestic violence is more concentrated in communities that experience poverty and street violence and have poor access to services, yet the harm done to children by family separation, particularly for indigenous and minority populations, must also be understood as a type of structural violence. But the converse is also true: a poorly functioning social welfare and justice system regularly fails children who need to be removed from parents who abuse them, a fact rarely explicitly acknowledged by policy makers.

It takes a village: the community's role

The empirical evidence on the role of community engagement in improving health outcomes for children and families is compelling, although the concept is not yet fully theorised.[129,130] Definitions of community are based on people's sense of belonging together, and the idea of communitas—inspired fellowship—which refers to shared experience and togetherness strengthened by rites of passage. However, all communities have hurdles to belonging, and the management of rights and responsibilities is an ongoing project. Communities can include and exclude, or have different forms of political meaning internally and externally.[131] Rather than thinking of communities as empty spaces in which policy and programmes paternalistically mould families into modern behaviour, nominally consult traditional authorities, or enable time-bound, project-defined community activities, an expanded vision of communities recognises their own active role and layered power relations that influence child health and wellbeing.

Community stakeholders span public and private services, formal and informal associations, traditional and modern worlds and, at times, syncretically cross these boundaries. Community groups can improve child health and wellbeing by sharing information, supporting each other, and building capacity among local stakeholders; advocating for external resources from district authorities; and building the confidence of people in poverty to ask why their entitlements are not being met. A large amount of literature supports the value of self-help groups and participatory learning and action groups in

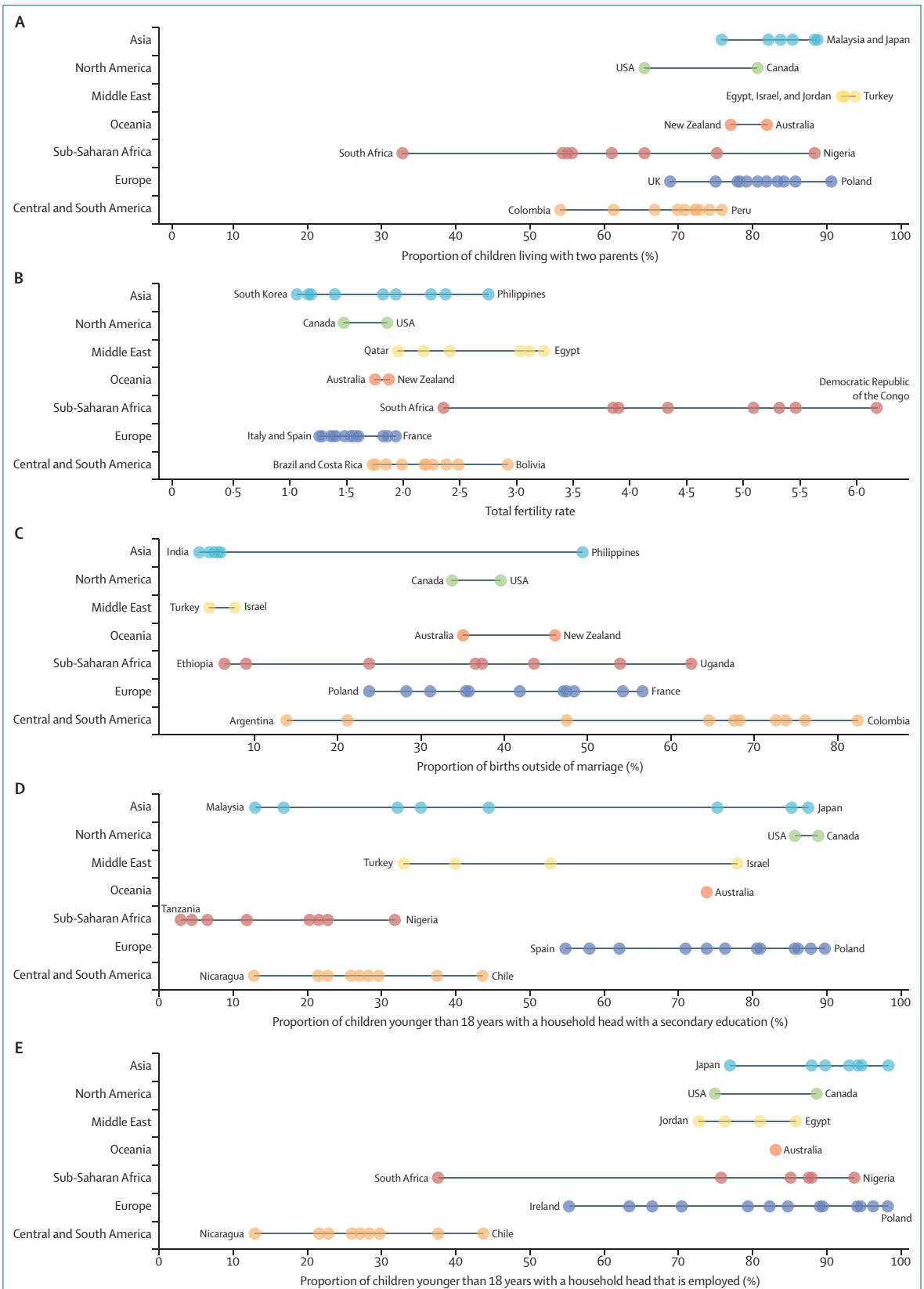

Figure 4: **Family characteristics in a sample of 60 high, middle, and low-income countries: proportion of children living in a household with two parents (A); total fertility rate (B); proportion of births outside marriage (C); proportion of children living with a household head who has a secondary education (D); proportion of children living with a household head who is employed (E)**

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improving maternal, newborn, and child health. Analyses of national data in India showed respondents from villages with a self-help group had 19% higher odds of mothers delivering in an institution, 8% higher odds of an increase in colostrum feeding, and 19% higher odds of using family planning products and services.[132] Large-scale cluster trials of community participatory learning and action women's groups in Nepal, Bangladesh, India, and Malawi reported a 30% reduction in newborn mortality, with substantial changes in preventive behaviours among attendants at birth.[133] WHO formally recommended the participatory learning and action approach, particularly for rural populations where newborn mortality is high.[134] Subsequent studies of the participatory learning and action approach using some of the 1 million accredited social health activists in India showed a 31% reduction in newborn mortality, as effective as the proof-of-principle studies.[135] These effects in eastern India were replicable and sustained.

Effects of community-level interventions on child nutritional status, and on determinants thereof (such as water, sanitation, and hygiene), have been more difficult to achieve. A Cochrane review to evaluate the effect of interventions to improve water quality and supply sufficient to maintain hygiene practices, provide adequate sanitation, and promote handwashing with soap, on the nutritional status of children, concluded that very few studies provided information on intervention adherence, attrition, and costs.[136] In 2014, a trial of India's total sanitation campaign (which aims to change social norms and behaviours, with technical support and financial subsidies) showed only modest changes in the uptake of household latrines and in reducing the amount of open-air defecation.[137] A review of the literature reported that water, sanitation, and hygiene campaigns reporting an effect on child diarrhoea and linear growth achieved high adherence via frequent household visits.[138] Nonetheless as improved water and sanitation can improve children's health and wellbeing through other mechanisms, such as reducing time obtaining and transporting water and improving girls' school attendance after they begin menstruating, it should be delivered as a government-funded intervention, with the collaboration of communities.

Community engagement can be more challenging in informal, urban settlements than in more stable, rural communities. Services and resources are managed by place; however, more agile systems are required to maintain responsiveness to changing needs given the fluid nature of urban migration and unregulated settlement. Informality poses specific challenges, including the challenge of access to health resources in urban areas.[139] Yet, a large study in the slums of Mumbai, India, suggests that solutions exist: local resource centres delivering integrated activities to improve women's and children's health in informal urban settlements increased met need for family planning (by 31% in intervention clusters compared with control clusters) and child immunisation rates.[140]

Community health workers are widely seen as a practical path to reach child health goals, particularly in rural and low-income settings. A review of the effectiveness of unpaid, non-professional volunteers and paid, professional health workers in malaria prevention, health education, breastfeeding promotion, essential newborn care, and psychosocial support showed benefits of varying degree in all categories.[141] Children's early development can also benefit from community health workers. In Pakistan, children who received responsive stimulation in a trial of female health worker home visits had statistically and clinically significantly higher development scores on the cognitive, language, and motor scales than those who did not.[142] In California, USA, a randomised clinical trial of the provision of in-person help to navigate relevant community services statistically and clinically significantly decreased reports of social needs by families and improved children's overall health status compared with controls.[143]

However, evidence suggests a high attenuation of these positive effects when governments take proof-of-principle community health worker studies and implement them on a larger scale, and more research is needed on performance and quality of care provided.[144] Two systematic reviews considered interventions on how to improve the performance of community health workers.[145,146] Implementation factors, such as recruitment, supportive supervision, incentives, community embeddedness (whereby community members have a sense of ownership of the programme and positive relationships with the community health workers), continuous education, and adequate logistical support and supplies are crucial for success. For example, in South Africa, a trial of improved training, continuous quality improvement, and mentoring of community health workers, increased the number of mothers breastfeeding their children, the number and quality of visits made to mothers, and the knowledge of mothers.[147] But too often governments and practitioners do not assess the relevance and feasibility of these strategies before implementation of community health worker programmes. Too little attention is paid to health system decentralisation, social accountability, and governance. Simply training more and more community health workers, without adequate support, is unlikely to bring benefit.

Power relations are a core part of how communities are constituted and reconstituted over time, including how social boundaries and norms are shaped and enforced. Unequal or oppressive power relations exist not only between marginalised communities and overarching structures (such as governments), but also within communities. For example, sexual-minority youth are at two to three times higher risk of suicide compared with their peers, a fact linked to non-accepting social environments and poor emotional and social support.[148] However, some evidence suggests that focused interventions can lead to positive outcomes. Community dialogues around issues,

such as caste discrimination and female circumcision, require delicate negotiations around social identity and direct challenges to illegitimate uses of power, but have been shown to facilitate changes to social norms when done sensitively.[149]

Some observers have expressed scepticism that participation leads to empowerment or to lasting and meaningful social change. They see poor engagement as a result of underlying power dynamics, and an undue emphasis on voluntarism as a failure to tackle the difficult politics of disempowering elites through specific pro-equality approaches.[150] Whereas, others believe that participation can lead to truly transformative outcomes in development, provided the approach taken is political, rather than technocratic.[151] Social movements can broker political alliances to transform the lives of many, examples of which include the anti-dam movement in India; the shift in control from economic elites to political parties in Kerala, India; participatory budgeting in Brazil; and the control of forests by local users in Nepal.[152] Larger social movements have a role to play in demanding the rights that communities need to care for children and provide for families.

Government as a project of shared responsibility to children

Safeguarding the health and wellbeing of children, like the health of our planet and environment, requires concerted public action. Governments are the natural locus of our shared responsibility for these matters, as such they have a central role in financing services for children, ensuring the effective delivery of services, and providing adequate social protection for families. Specific governance arrangements at national and subnational levels are further developed later in the Commission, wherein we explore issues of multisectoral collaboration and links between different local, regional, and national governments.

In countries of every income, governments have a central role in the public financing of services for children. Only public financing (tax financing or social insurance) can ensure equitable access and provide financial protection against the cost of using services. Experiences from HICs show that different models of service provision for children and families can work, from predominantly public to mostly private, as long as public financing has a central role. In these countries, delivering children's entitlements—security, health care, immunisation, water and sanitation, education, and social protection—is a responsibility primarily for the public sector, which can alternatively contract out to private or non-governmental partners under government supervision.

In LMICs concerns exist that some governments face enormous challenges in delivering even the most basic services, and some evidence suggests that non-state actors can provide these services more effectively in some cases. For example, trials in Kenya and Liberia have shown in head-to-head comparisons that the same programmes are less effective when put in the hands of government compared with private providers.[153,154] A meta-analysis of trials evaluating a wide range of health, education and social assistance interventions finds that those implemented by government are on average less effective than non-state providers.[155] These studies typically focus on not-for-profit organisations and less evidence exists for the value of contracting for-profit providers, whose involvement remains controversial.[156]

However, in many LICs, government must retain the primary role for service provision for two reasons: first, only the government in these settings has the capacity and mandate to reach a large proportion of the population; and second, the ability of the national government is likely to be too weak to manage and monitor numerous complex contracts with private providers. These factors gives rise to the question: how can countries improve the effectiveness of their government bureaucracy? This question is government-wide, not about any one sector; therefore, it has resonance for delivering services to improve child health and wellbeing, which span multiple sectors.

Countries can improve the effectiveness of the government bureaucracy to provide the over-arching services children are entitled to by focusing on better management practices, particularly for middle-tier bureaucrats. Front-line public sector workers or so-called street level bureaucrats[157] have been the focus of many studies, which have tested ideas focusing on the selection and recruitment of public officials,[158] pay for performance,[159] prosocial motivation,[160] and career concerns.[161] However, the role of middle tier bureaucrats—those who sit between senior civil servants and front-line workers, responsible for transforming political preferences into policy and implementation—is often under-appreciated. In-depth studies in Nigeria[162] and Ghana[163] show that management practices are critical determinants of bureaucratic performance. Practices related to autonomy are positively associated with better public service delivery, but practices related to incentives and monitoring of bureaucrats are negatively associated with performance, suggesting that countries with low levels of state capability might benefit from providing public servants with more autonomy. Further work in this area emphasises the important role of management at the district level,[164,165] which is a key governmental tier for delivering child health services.[164]

In all cases, governments play an irreplaceable role in reaching the poorest and protecting the most vulnerable members of the population, and social protection for children and families is a key responsibility. According to the Social Protection Floor Initiative,[166] every person is entitled over their lifespan to basic health care and basic income security as part of a comprehensive social protection package. However, more than one in three people, and more than half in rural areas, worldwide do

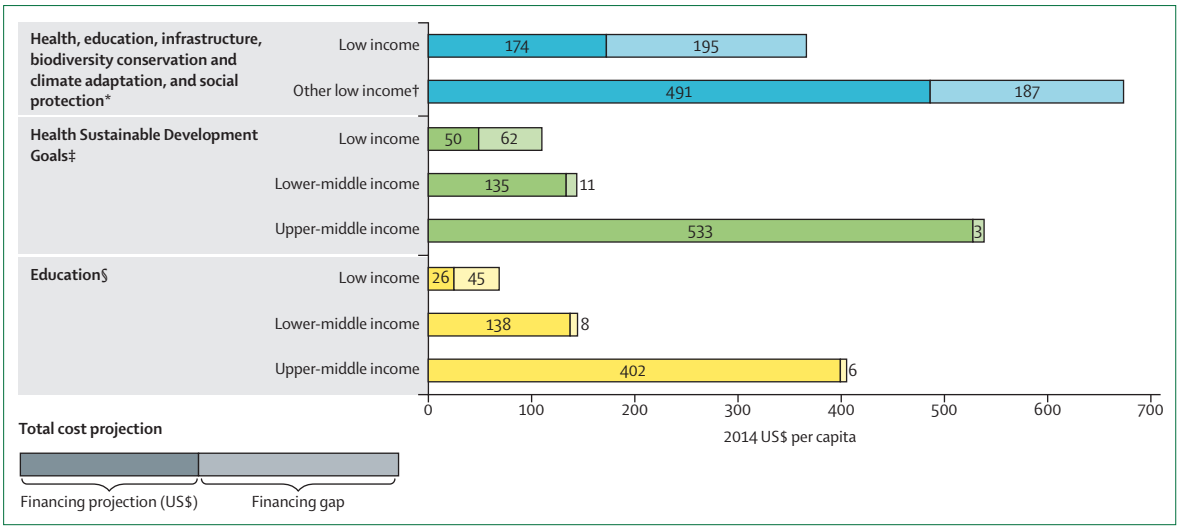


Figure 5: **Estimated costs & financing gaps for the Sustainable Development Goals**
*59 countries, 2018–30, US$2014 per capita. †Other low-income countries have a per capita income of between $996 and $2700. ‡Coverage expanded for close to 200 interventions recommended by WHO to advance the health Sustainable Development Goals, with associated costs for health system strengthening (67 countries, 2016–30, $2014 per capita); not all countries had a funding gap, if the subset of lower-middle income and upper-middle income countries with a financing gap were examined the gap would be $51 per capita for the lower-middle income countries and $66 for the upper-middle income countries. §Preprimary, primary, and secondary education (2015–30, $2014 per capita). For the methodology and sources see the appendix pp 3–4.

not have health protection by legislation, affiliation, or health insurance—although this is affordable in all countries.[167,168] In western and central Europe health care protection coverage is almost universal; whereas, in Asia and the Pacific 40% of the population and 70% of the population in Africa are without health-care protection, despite several studies showing protection affordability.[168,169] For families providing support to a disabled child the costs of health care might be prohibitive and place a huge burden on them. Many countries need to take further steps to develop strategies to harness existing resources, with analysis of the relationship between type of risk and health care protection financing.

Social protection measures (including social health insurance and tax financed health care), like all public expenditures, can be more or less equitable. According to the latest evidence from the World Bank ASPIRE database on the distribution of social protection spending, the richest fifth of the population takes up about three to four times more social insurance resources than the poorest fifth in the average country. Health insurance and social protection are important instruments to ensure universality and equitable access to health-care services by children and their families. The difference between urban and rural health-care coverage attests to the difficulties in relying on the community or other small scale ways of pooling resources and sharing risk. A universal approach, primarily funded through general (progressive) taxation (and with development assistance in the poorest countries), is the best option to finance health-care coverage for the entire population, in particular those who cannot contribute, such as informal workers or women excluded from the productive sectors.

Financing governments' efforts for children and the SDGs

To achieve the SDGs and deliver the entitlements previously outlined, many countries will need to invest in the scale-up of high-quality services across sectors. Several studies have investigated the cost of this scale-up through so-called SDG price tags and compared these costs with projections of financing likely to be available under different scenarios. Such analyses are not child specific and are inherently uncertain, but they do give a sense of the order of magnitude (figure 5). In the health sector, the cost of scaling up priority interventions and strengthening the health system to meet the SDGs by 2030 is estimated to be on average $112 per person in LICs and $146 per person in lower-middle income countries.[170] Projections suggest that some countries will not be able to finance these costs, generating a financing gap of $62 per person in LICs and $11 per person in lower-middle income countries (appendix pp 3–4). Equivalent figures are available for education.[60] In 2018, an analysis of all the SDGs that combine sector specific costs reported a substantial financing gap of $195 per person (figure reported according to the value of US$ in 2014 for comparison across studies).[171] These global estimates are preliminary, and more precise estimates will require country specific analyses based on local data.

Mobilising more public financing from domestic resources will be key to providing predictable and sustainable funding to achieve the SDGs. As trends in health and education over the past few years show, countries rely increasingly on government spending from domestic resources and less on development assistance.[60,172] To mobilise more domestic spending, countries will

***Panel 6*: Getting governance right for children—key messages**

- National governments are the lynchpin of efforts to deliver children's entitlements
- A powerful new framing of children at the centre of the Sustainable Development Goals can help build national political priority and raise domestic financing
- Deliberate design choices are required to ensure different sectors act jointly for children
- Local governments link national governments to families and communities, but require support, finance, and devolved power
- Fragmented global governance could be ameliorated by a powerful new framing around child rights and the Sustainable Development Goals

need to maintain economic growth, improve their taxation capacity, and prioritise the SDGs in national and subnational budgets. If countries increase taxes it should be done in a progressive manner. Countries should explore the wide range of options for domestic financing (discussed in further detail later). Considerable scope also exists to improve efficiency (eg, 20–40% of worldwide health expenditure is estimated to be wasted) by reducing waste, tackling corruption, and allocating government spending towards effective interventions both within and between sectors.[173]

Development assistance will continue to be a vital source of funding in the poorest countries. If bilateral donors were to increase spending to the 0·7 percent of GDP benchmark (adopted by the UN General Assembly in 1970 and repeatedly re-endorsed), this would increase international aid substantially. There is great potential to redirect and target existing aid to SDG-related activities in LICs, and away from middle-income countries (MICs), which currently receive a sizeable amount of aid in absolute terms (often earmarked for specific diseases or programmes). Beyond traditional channels, a range of other financing ideas have been proposed.[171] They include improving tax administration by addressing tax evasion strategies, such as profit-shifting by large multinational companies, and implementing a range of new taxes, such as a global carbon tax with the proceeds directed to the SDGs, a financial transaction tax, offshore accounts tax, high net-worth individual tax, and a tech tax on the natural monopolies emerging in the tech industry. Blended financing instruments, such as the Global Financing Facility, The Vaccine Alliance, and the Global Fund also hold promise in using development financing to leverage additional domestic and commercial resources towards the SDGs.

Summary

Here, we have laid out a set of entitlements for children. We examined how children themselves can participate in reclaiming their rights, and the responsibilities of families, communities and governments in ensuring them. Next, we take a detailed look at how multisectoral governance arrangements can be reshaped to deliver children's entitlements now and in the future.

Getting governance right for children

The task of achieving the SDGs should galvanise governments to deliver the rights and entitlements of children and young people, but child advocates and governments must generate the political priority and build fiscal and administrative capacities to do so. In the SDG era three leadership and governance challenges stand out: first, how to move interest in child health beyond the health sector to develop holistic, integrated national policies for children, with augmented governmental capacity to carry them out; second, how to empower subnational and local governments to take multisectoral action; and third, how to reform and integrate the global governance architecture and develop new global agreements pertaining to children to support such multisectoral action (panel 6).

National governance: how to make children a priority, mobilise funds, and organise action

National governments are the lynchpin of efforts to deliver child entitlements: realising the rights of children to health and wellbeing depends on the leadership and commitment of governments, aligned institutional incentives and accountability across sectors, increased financing, and robust legislation.

Building political priority and mobilising domestic resources

For national governments, child wellbeing is rarely an explicit concern for top political leaders (eg, heads of state and prime ministers), and usually is handled by specific government departments (eg, social welfare, health, education, or youth) that might not possess the political leverage required to work across sectors to achieve their aims. A handful of countries have developed over-arching policies backed by national programmes dedicated to child wellbeing, including Ireland, New Zealand, Uganda, and the UK, but policies in most countries are not cohesive and do not have sufficient political force, including those with national Children's Commissioners. Many programmes are under resourced. Moreover, attention given to various dimensions of child wellbeing is patchy, with some areas (such as child survival) receiving substantial resources and others (eg, protection against environmental pollution and violence) considerably less.[174]

Stakeholders must be deliberate about building political priority and mobilising domestic resources for children. Policy reform explicitly decides who receives valued goods in society, but power dynamics are underappreciated in policy processes of health and other social sectors.[175] Emerging literature on how to build nationwide political prioritisation for health issues provides some lessons. Specific policies can be advanced directly, when political authorities focus attention on issues, harness financial resources, control regulatory regimes and pressure policy actors, or indirectly, when they create institutional incentives and set up trade-offs with other priorities.[176–179] Case studies of successful advocacy efforts

suggest that strategies for positive change, although context-specific, pay heed to leaders' need to maintain political legitimacy (in whatever form),[177] as well as the formation of healthy coalitions that can support and propel policy ideas. Advocates for children have the advantage of possessing a winning argument from multiple standpoints: affective, ethical, economic, and financial. Advocacy and coalition-building efforts for children can benefit from the built-in infrastructure of countries' efforts towards the SDGs, newly reconceptualised around the figure of the child, as previously argued in this Commission.

Political prioritisation is a prerequisite of and an accompaniment to mobilising domestic resources in all countries—for all sectors that contribute to child health and wellbeing. LMICs fund most of their social sectors through domestic resources, with a few exceptions, and this reliance on domestic resources will only increase as official development aid continues to recede in importance for most countries' economies. Development assistance now accounts for less than 1% of all health spending, and projections suggest it will reduce further,[180,181] although for a handful of countries it remains an important, albeit volatile, source of financing (in many countries it still remains important for funding of activities for marginalised populations).

Given these trends, most governments will require even greater domestic financing to meet the investment needs of children.[182] As noted by the WHO Commission on the Social Determinants of Health[183] a decade ago, rich countries essentially choose their amount of child poverty through the redistribution policies they enact. In many emerging economies there is fiscal space to boost spending on children, across all sectors. Reprioritising spending towards the needs of children and improving efficiencies in the use of funds is possible in all countries, and doing so opens the opportunity to improve equity, as governments have the ability to pool resources and ensure financial protection for households. Enormous variation exists across countries regarding the extent to which governments prioritise health, education, and other social sectors within their budgets. Historical data can be useful in providing a benchmark for what might be feasible. For example, if the government of India were to spend 5% of GDP on health, matching the percentage spent by many LMICs, this would increase domestic government health spending by four times.[184]

In addition to reallocating existing funds, countries can also seek to increase the total amount of funds available. Governments can increase tax revenue through smart policies and administrative reform, to raise funds for children in the general budget (figure 6).[185,186] So-called health taxes, such as those on sugar, tobacco, and alcohol, are not only important for reducing consumption of unhealthy substances, but they can help generate revenue for health. However, mobilising a fair tax system

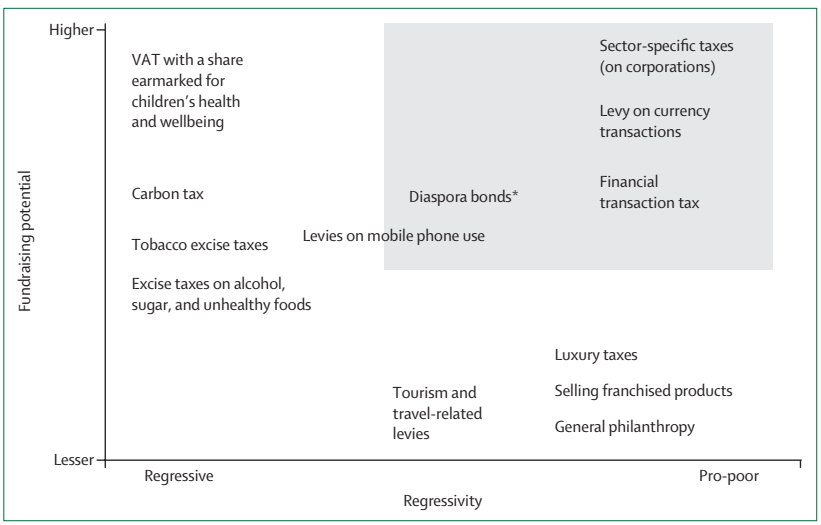


Figure 6: **Domestic financing initiatives available to policy makers**
VAT=valued added tax. *Diaspora bonds are financial instruments issued by countries targeting expatriates living in wealthy countries; diaspora members purchase bonds issued by the government despite lower interest rates and returns, typically for patriotic reasons. Such a system has been successfully implemented in Israel.

is much more important: one which uses all modalities, especially genuinely progressive income taxes, with a shift from income towards carbon taxes, and broad-based consumption taxes, which are regressive and need explicit balancing of their potential negative effects on income and wealth equity. Revenues should be shared across sectors contributing to improving child health and wellbeing, and the share of the budget devoted to children should be monitored by the national government and compared internationally.

The extent to which a country can tap into each of these channels will vary on a case-by-case basis; however, what is common across countries is the central role that the ministry of finance will play if domestic resources are to be mobilised for the SDGs, echoing the need for the prioritisation of child health and wellbeing by senior government members. Those advocating with finance ministers for more investment in children need to forcefully make the case that such spending is not only good for their wellbeing, but also for productivity and the economy. Advocates must engage with the national budgeting process and communicate using language that is understood by finance ministers.

Many economists, including Nobel prize winners Joseph Stiglitz and Paul Krugman, have described the harm done by neoliberal austerity policies. Clear evidence shows that austerity cuts welfare benefits, increases inequality, and harms the poorest families the most. The proponents of austerity say it is necessary to cut national debt. Yet these policies often actually increase the national debt burden—in the UK the national debt increased by £860 billion from 75% to 85% of GDP between 2010 and 2018. So, in arguing for investment for children, advocates should contest the arguments put

***Panel 7:* Case study of multisectoral partnerships: Chile Crece Contigo**

Chile Crece Contigo, or Chile Grows With You, is a programme to help all children reach their full potential by providing coordinated services across public sectors, from the prenatal period to 4 years of age. The programme was introduced by then President Michelle Bachelet, a paediatrician by training, adopted by law in 2009, and implemented nationwide, financed by a permanent line in the national budget.

According to a case study by Milman and colleagues,[198] Chile Crece Contigo was found to be cost-effective and associated with a decrease in the proportion of children younger than 5 years old with a developmental delay, from 14% to 10% over the 10 years of its implementation. Nearly three-quarters of beneficiaries described the programme as being central to their experience of pregnancy and parenting, suggesting high satisfaction with its services.

The success of Chile Crece Contigo is predicated on a sophisticated design for multisectoral collaboration. First, the programme's introduction, in addition to being backed by senior political leadership, was characterised by deliberate consensus-building by a broad swathe of technical and political stakeholders at national and regional levels. Such early consultation led to buy-in and investment by all sectors. The programme is housed in the Ministry of Social Development, selected for its longer experience of coordination between sectors at national, regional, and communal levels, compared with the ministries of health and education, which are nonetheless highly involved in delivering services. Implementation of the programme builds on existing systems within all three ministries and pre-existing municipal networks for community-driven programming. Financing is centralised through the Ministry of Social Development, with transfer agreements for funds specifying technical standards for the government to monitor and manage quality of services.

Feedback loops for monitoring and evaluation, including periodic reviews, have identified some areas for systems strengthening, such as around fund transfers to institutions and integration with other government data systems. Ideally, these feedback loops will allow continued improvement in the Chile Crece Contigo programme and provide a basis for multisectoral collaboration that is broadly applicable to child health and wellbeing programmes in other countries.

forward for austerity policies being necessary for national debt reduction.

Finally, so-called child-friendly budgeting has been used in some countries to quantify total public spending on children and adolescents, including both direct expenses (such as for vaccination and primary education) and indirect expenses (including food support or cash transfers to families). In a review of 14 country experiences, ministries of finance and planning usually oversaw the process and involved stakeholders from diverse sectors.[187] In Mexico and Peru, measurement exercises were conducted during the preparation phase of the budget cycle, allowing for planned expenditures on children to theoretically influence budget decision making. Child-related expenditures did rise, although no direct evidence suggests that child-friendly budgeting processes were the cause of this increase. However, in all surveyed countries, the findings of measurement processes were publicly released, providing improved transparency of child-focused spending. Further research is required to determine whether child-friendly budgeting can be an effective tool to improve domestic resource mobilisation for child health and wellbeing.

Take deliberate action to coordinate and share responsibility for children across sectors

As previously discussed, all sectors have a role to play in promoting children's health and wellbeing, and the evidence is clear on the need for multisectoral action for children.[188] However, ministries responsible for different aspects of child wellbeing rarely coordinate well.[189,190] Several factors perpetuate this problem. One is national financing arrangements, which are siloed by ministries,[191–193] a problem compounded by poor impetus for multisectoral coordination in national cabinets. Inter-ministerial politics, competition for annual budgets, and interpersonal rivalries are further obstacles.[194] Insufficient country experience and capacity for planning policies across sectors is common, and stronger mechanisms are needed to help sectors coordinate.[195] Finally, even when policies are coherent, they are rarely backed by costed and funded implementation plans.[189,196]

The SDGs provide an opportunity to address these challenges head-on. Although the evidence for what works is not yet robust,[199] some key strategies are available to support improved multisectoral governance and execute the political push to move forward on a child-centred SDG agenda. Specifically, executive pressure must bring the sectors together; make clear roles and responsibilities for each sector, with clear accountabilities and indicators; ensure financing from a coordinating source to be used as incentive and facilitator; and use cross-cutting ministries (such as ministries of finance, planning, or social welfare) to validate, coordinate, and share data. In Chile, executive leadership and cabinet buy-in were essential to drive coordination across sectors, with the strong involvement of cross-cutting ministries. Chile's multisectoral programme for improving early childhood development (*Chile Crece Contigo*; panel 7) provides a model for defining roles and budgets across sectors, and financing and monitoring systems that encourage collaboration.[54,198]

Policies across sectors must be examined for their potential effect on child health and wellbeing. The content of these assessments could draw from the child entitlements framework, discussed earlier, and by reviewing existing guidance from UNICEF and the World Bank,[199] on integrating a child focus into poverty and social impact analysis, and from the work of national governments, such as New Zealand, which has introduced a budgeting approach in which cost-benefit analyses are based on current and future wellbeing. The Health in All Policies discourse also provides technical tools and resources.[200] These efforts should be flexible, ideally using mechanisms within each country government's own structures, and linked to existing country reviews taking place under the auspices of the CRC.

Success is predicated on the basis of a sophisticated understanding of the key actors, their incentives and constraints, and the functioning of the overall political ecosystem, with distributed leadership that engages a

broad coalition of stakeholders.[201] Tools for political economy and power analysis are available to map key actors and institutions and understand their potential interactions, but are under used. Such analyses, along with a sophisticated framing of child wellbeing that appeals to all, can be supported by global agencies, but must be led by country institutions as part of their political prioritisation and multisectoral action. The over-arching goal must be sharing the responsibility of child health and wellbeing beyond the health sector, and instituting mechanisms of governance, financing, and accountability to do so. Specific attention should be paid to changing the lens of the health sector itself to recognise the contributions of other sectors and work with them as equal partners. The pitfall of so-called health imperialism (in which stakeholders in the health sector assume that health interests predominate) can alienate other government departments that, understandably, hold different priorities.[202]

Empowering local government in municipalities and districts

As intermediaries between national governments and communities, local and municipal governments hold an essential responsibility in the improvement of child and youth wellbeing. However, local and municipal governments face a number of challenges and their capacity to effect change is often small. Strong local governments, with deliberate multisectoral governance models, can translate children's entitlements from national governments to families and communities.

Strong local governments link households and communities to national initiatives

Ideally, local governments address the local social determinants of health, implement public health policies and programmes for children and young people, and coordinate multisectoral action for the children most affected.[203] District and municipal authorities are often focal points in convening and coordinating the actions of multiple actors. The capacity of local government to manage relationships, improve synergies, constructively resolve conflict, and mobilise populations, is an essential role in the SDG era.

However, a review of child policies from countries as diverse as Moldova, Malawi, Jordan, and Cambodia revealed several common challenges.[190] Vertical coordination between national and subnational governments created challenges in balancing divergent priorities, revision of policies that did not account for local context, management of overly-centralised or overly-decentralised coordination mechanisms, and tension between national and local control over budget management often in the face of weak local capacity. Local governments are often caught between the competing priorities of governments, donors, and implementation partners, and sometimes the local interests of powerful extractive, agricultural, service, or manufacturing industries. Particularly in donor-dependent countries, poor local government capacity has prompted authorities to turn to international and local non-government organisations to assist with provision of services.[204]

Local authorities' ability to act depends on political circumstances, the status of decentralisation, and, most of all, budgetary power, coupled with the extent to which the national government supports the activities of local governments. One reason progress towards the implementation of child-focused initiatives is patchy is because of more or less successful modes of decentralisation.[205,206] Little evidence is available on the effects of decentralisation on equity and efficiency of service provision.[207] Countries often aim to use decentralisation to enhance local democracy, reduce bureaucracy, and promote client-oriented services (including high-income Nordic countries, such as Denmark and Sweden,[208] and lower-middle income countries, like Kenya[209] and Indonesia[210]). In countries with weak governance arrangements and budgets, such as Sierra Leone, fractured national mechanisms for child protection systems can be amplified locally[211] because of weak staff performance, poor understanding of cultural and social norms, and negative perceptions of central government.[212] Similarly, coordination efforts for child protection in South Sudan have been hindered by a decentralised system with unclear channels for communication across the national and local governments.[213] While devolved responsibility to local government makes sense to link children's families and communities to nation-wide initiatives, it requires thoughtful support and strengthening of local systems. Decentralisation is not a panacea, and it can be well or poorly executed, but it does offer opportunities to strengthen child health and wellbeing.

At the same time, local governments are meant to be accountable to the communities they serve. Certain legal, fiscal, and administrative frameworks are more effective when it comes to incorporating community voice and action, including that of children and youth. In Brazil, participatory management councils, which are part of municipal governments, are enshrined in the constitution, and municipal laws exist to support children's councils, which have a small budget at their disposal.[214] In Nicaragua, child and youth participation in local governance is facilitated by support from family and teachers, alliances between local authorities and civil society, and leadership in children.[111] However, such municipal councils might be harder to create and sustain if not protected by the law.

Similarly, child-friendly cities are those whose system of governance is committed to fully implementing the rights enshrined in the CRC. They translate national commitments into local action, often making institutional, legal, and budgetary transformations. For example, in Alexandria, Egypt, a child-friendly city initiative launched in 2006 established a coordinating mechanism to strengthen the protective framework for children, resulting in the identification and referral of more than 7000 children at risk to appropriate services.[215] However, in

many LMICs, governments that ratified the CRC do not have sufficient financial resources and political capital to support systemic reforms called for by the treaty.[216] In the poorest countries, budgets might remain unspent or be reallocated elsewhere. Efforts to support child-friendly cities are often spearheaded by non-government organisations, such as Child in the City, or development agencies, such as UNICEF, and not by local authorities themselves. These deficits can be mitigated by enhanced national political prioritisation of children.

Successful multisectoral governance at local level: the devil is in the detail

Local multisectoral governance represents a missed opportunity for efforts around child health and wellbeing. Multisectoral collaboration might be easier to achieve in local government given that different departments and personnel are often closely located and know one another.[217] Barriers to collaboration between local government and civil society organisations, citizen groups, and the private sector might include structural, procedural, financial, professional, and legitimacy issues.[218] However, solutions do exist, for example barriers associated with traditional hierarchical governance arrangements can be overcome by so-called network governance formations, in which a broader group of experts meets to solve problems in a neutral space, rather than some actors fulfilling the orders of others.[219]

Where local initiatives for children's wellbeing have proven sustainable and effective, certain conditions that encourage multisectoral action have been in place. In a review of Overseas Development Institute case studies, multisectoral partnerships and action with community groups, schools, places of work, and local interest clubs were particularly effective when there was clear decentralisation and task-shifting. Joint governance and service delivery models across education, water and sanitation, and other sectors were associated with improvements in health, equity, and more efficient use of resources.[188,220] Local governance can also link multiple sectors and governmental jurisdictions, and mobilise and convene communities and institutions, by attracting and empowering local champions and social entrepreneurs for child and youth wellbeing. In the UK support for multisectoral approaches (ie, between health and education), used local champions to establish partnerships, plan action jointly, and promote the required programme changes.[221]

Building strategic and operational capacity enables local authorities to operate autonomously. Effective programmes use strategic partnerships to take advantage of power distributed through networks and influential actors in the broader economy. Long-term partnerships; shifts from programmatic to systemic approaches; and networking with school boards, law enforcement, local business, and parent groups are essential to help local authorities. Another example are the after-school programmes for sports and other activities developed in the USA, developed when municipal leadership convened, built a vision, and used community mobilisation to leverage local policies and infrastructure, even in the absence of financial resources.[222] More broadly, political leadership and public participation were identified as the most important factors for multisectoral action across all stages, from initiation of an endeavour towards maintaining interest during the implementation phase.[217,223] Feedback loops to inform higher levels of government are also needed to allow scale-up of local innovations in successful programmes.

Global governance

In the age of globalised public health, many threats to child wellbeing cross national boundaries. Global governance arrangements influence a government's capacity to deliver for children, but these global schemes are currently fragmented and require urgent attention to be more effective.

Redesign global governance for the SDGs with the narrative of children at the centre

Global health governance is a highly contested sphere,[224] and a powerful new vision has yet to replace child survival, used as the dominant heuristic from the 1990s through the Millennium Development Goals era.[225] Nominally organised around the Survive-Thrive-Transform framework of the Global Strategy for Women's and Children's Health (2016–2030);[134] nonetheless, global governance for child health and wellbeing is fragmented and disjointed. Although the CRC offers a framing focused on rights, some organisations have argued that the case for children should be based on wellbeing, with a focus on objective and subjective assessments of life satisfaction.[226,227] Others say the rights and wellbeing framings are compatible, or offer framings focusing on human capital and capabilities.[228]

All of these frameworks capture important aspects of the health and welfare of children, but to-date few have offered a comprehensive narrative that conceptualises placing children's health and wellbeing at the centre of the SDGs and the notion of sustainability.[229] Such a framing is urgently required, not only to propel political momentum and provide a common vision for international organisations, national governments and civil society institutions, but also to breathe life into reforms of the global governance architecture, including the UN. The SDGs disperse discussion of the child across multiple goals—an intentional decision because the SDG agenda is meant to be indivisible and integrated. But, despite much rhetoric, international institutions have not been transformed and have seen their budgets stagnate, and global governance remains structured to deliver the Millennium Development Goals rather than the SDGs.[230]

As the key UN agencies concerned with children's health and wellbeing, UNICEF and WHO must lead on a

new and integrated SDG agenda, with children at the centre. The leadership of these agencies must heed recent learnings about global health networks, which are most effective when they strategically frame their issue and succeed in establishing political coalitions that extend beyond the health sector.[231] Findings from the Global Health Advocacy and Policy Project suggest that while new technical advances, global agreements, or initiatives to counter industry can be key in fomenting global movements, in all cases, success is predicated upon collective action taken by united stakeholders who had previously worked in isolation. To unite diverse stakeholders in the SDG era, child health and wellbeing must be framed both as preconditions and outcomes of sustainable development, to involve other sectors in an integrated manner.[232] Fortunately, the connections between child health and other SDG priorities are strong and reciprocal: the first step to establishing partnerships between sectors is to map these connections and assess their strength and directionality.[233]

International organisations largely pursue sectoral rather than holistic strategies to advance the rights and wellbeing of children. They focus not on the child per se, but rather on discrete aspects of child wellbeing—health or specific diseases, education, nutrition, care, protection, violence, youth employment, or another concern—despite the fact that these dimensions are intertwined.[234–236] Some organisations appear to be exceptions to this sectoral orientation, such as UNICEF and Save the Children; but even these institutions divide themselves into multiple programmatic areas. Sectoral divisions parse problems to make them manageable; for example asking an immunisation programme to promote literacy is unreasonable, but suggesting that interactions with children and families around immunisation could provide an opportunity to address other social concerns around the child is plausible. Integration must be achieved at an institutional level: UN institutions, such as WHO and UNICEF, should be leaders in creating partnerships internally, with each other and with other UN and international institutions, modelling what will be required nation-wide to work across sectors. Specific technical expertise on organisational design and management might be needed from experts in this area, backed by a strong mandate from institutional leadership.

Making global governance work for countries

Since Jan, 2017, António Guterres, UN Secretary General, has tried to reduce fragmentation by bringing together the UN architecture to enhance lateral collaboration. Separate UN funding streams, turf wars, duplication of plans, and bureaucratic inefficiencies abound. An umbrella strategy across agencies could enable multiple actors to work in tandem for the child and their families, provide concrete strategies to deliver entitlements, and uphold principles pertaining to rights and access to services. To lead on this agenda, WHO must reorient from its historically biomedical vision and work with UNICEF to engage with ministries other than departments of health. The UN Committee on the Rights of the Child, the expert body tasked with monitoring compliance with the CRC, could also play a role in supporting the roll out and management of such a strategy to achieve the agenda laid out in this Commission. Whether such coordinated action can succeed in pushing forward this programme will be the measure of our global leaders' ability to go beyond the usual ways of doing business to fulfil our responsibility towards children and their future.

One major and well known obstacle to more coordinated global governance is that the priorities of global institutions often do not align with the needs of individual countries.[237,238] Institutions like the World Bank, the United States Agency for International Development, The Vaccine Alliance, the Global Fund, and the Bill & Melinda Gates Foundation possess major financial and technical resources, which their leaders often use to, in effect, impose priorities on national governments. Global bodies are often criticised for being insufficiently attentive to the expertise and understanding of local needs and local actors. The result is a plethora of initiatives concerning the child, which do not necessarily align with national priorities, and divide and distort governmental attention and resources.[227] Commitments made by global leadership bodies (WHO and UNICEF) in 2018 have the potential to mitigate many of these challenges, but their realisation is still pending.[239]

Global norms, such as the ones considered and advocated for in this Commission, are often refracted and altered when translated to regional, national, and local governments, a process that has been described as norm localisation.[240] The legitimacy and authority of global norm-setting exercises, including Commissions published by *The Lancet*, rarely reach implementation level. Over the past few decades, regions have become substantially more important sites of cooperation in the architecture of world politics.[241] Regional bodies might be useful in mediating and translating proposed norms around child wellbeing, sustainability, and the SDGs. Regional bodies can also advance policy issues in ways that can inform global policies and recommendations, as seen with the work on data protection and online privacy for children by the EU, advocacy for malaria control by African Union, or the support of the South Asian Association for Regional Cooperation for child nutrition initiatives.

Summary

Here, we reviewed challenges and opportunities for improved governance at national, subnational, and global levels, and discussed how flatter, networked models might need to replace traditional hierarchical modes to implement the multisectoral SDG agenda for children. The fragmented global governance architecture also needs major surgery, with a shift towards the involvement

***Panel 8*: Regulating commercial marketing to children—key messages**

- In countries around the world, children are highly exposed to the marketing of products that are harmful to their health and wellbeing, through techniques that exploit their developmental vulnerabilities
- Children's online exposure makes them vulnerable to the exploitation of their data, images, and person; however, internet access also creates opportunities for accessible and effective health promotion activities
- Ample evidence shows that voluntary self-regulation by industry does not work
- Adding an Optional Protocol to the Convention on the Rights of the Child on the regulation of commercial marketing would be a strong step towards protecting children from its harmful effects, and should be pursued by a broad coalition of countries, UN agencies, and civil society organisations

of regional bodies. We now extend this discussion of improved governance structures to the commercial sector.

Regulating commercial marketing to children

Unregulated commercial activity poses many well documented threats to children, not least environmental ones. However, commercial marketing of products that are harmful to children represents one of the most underappreciated risks to their health and wellbeing (panel 8). We have examined the harms children suffer from commercial marketing, looked at the insufficiency of voluntary regulation, and propose a political process to control commercial marketing to children by developing an Optional Protocol to the CRC (ie, an additional component to the treaty that must be independently ratified).

Children are enormously exposed to harmful commercial marketing

Children around the world are exposed to severe threats from the commercial sector, by advertising and marketing that exploits their vulnerability, by governments not regulating products that harm their growth and development, and by use of their data and images without their knowledge and permission. According to Kickbusch and colleagues[242] approaches to health promotion have "totally underestimated globalised corporate power combined with its global marketing onslaught and its transnational influence on political decision making," a discussion that has yet to be explicitly extended to children. Countries and civil society organisations have not been able to check the power of commercial entities, especially multinational corporations, which exacerbate social and health inequities.[243]

Awareness is growing of the harm of products marketed to adults for use by children. For example, inappropriate use of breastmilk substitutes is associated with lowered intelligence, obesity, and increased risk of diabetes and other non-communicable diseases, collectively accounting for an estimated loss of $302 billion.[244] But marketers also target children specifically. Marketing of products to children and adolescents provides excellent dividends for companies, driving household spending, and creating brand loyalties across the lifespan. Large companies incorporate the science of the life course approach into their marketing, to achieve the adherence and fidelity of children to capture future consumption. This life course brand loyalty constitutes an even more valuable target than the spending children currently direct or influence.

Children around the world are enormously exposed to advertisements: the average young person in the USA sees 13 000–30 000 advertisements just on television each year.[245] A systematic review showed that the most commonly reported persuasive techniques used on television to promote food to children were the use of premium offers, promotional characters, nutrition and health-related claims, the theme of taste, and the emotional appeal of fun.[246] Additionally, the channels to reach children and adolescents have grown and diversified, often blurring the line between entertainment and advertising. Social media advertising has exploded in the past decade; however, little research is available to understand the effects of reaching children directly with commercial messaging.[247] Newer techniques, such as the use of so-called kidfluencers (social media endorsement deals for children and teenagers), are barely on the radar of parents and regulators.[248] Although children younger than 7–8 years old are understood to believe what they see and not to recognise the persuasive intent of commercial advertising and marketing, much less is known about how emerging technologies potentially exploit children's developmental stages for the purposes of profit making.

Children are the frequent targets of commercial entities promoting addictive substances and unhealthy commodities, including fast foods and sugar-sweetened beverages, but also alcohol and tobacco, all major causes of non-communicable diseases.[249–252] Unhealthy food advertising on television is an important contributor to childhood obesity, with attendant effects across the lifespan. A review of 23 studies in Latin America reported that advertising exposure was associated with a preference for and purchase of unhealthy or low-nutritional value foods by families and children with high body-mass index, overweight, and obesity.[253] A study, published in 2016, showed that the link between television viewing and poor diet was strongest for children who watched the most commercial television, and for those who were actually exposed to advertisements embedded within programmes.[254] In Iran, food advertising during children's programmes is dominated by food items that are potentially harmful to oral health,[255] as are nearly two-thirds of food adverts during UK children's television.[256]

One study has also expressed concerns that toy advertisements on television, which target children, promote sedentary play.[257]

Children worldwide are also highly exposed to advertising for products nominally for use by adults only, such as alcohol, tobacco and e-cigarettes, with exposure to advertising associated with greater consumption. In Australia, alcohol advertising and audience viewing data were purchased for all football, cricket, and rugby league TV programmes for 2012, with a cumulative audience of 26·9 million children and adolescents, and 32 million young adults. Results showed that children and adolescents were exposed 51 million times to alcohol adverts, with 47% of this exposure occurring during the daytime.[258] In a study of 11–14 year olds from Los Angeles, CA, USA, African-American youth were exposed to an average of 4·1 alcohol adverts per day and Hispanic youth were exposed to an average of 3·4 alcohol advertisements per day, nearly twice as many as non-Hispanic white youth, who were exposed to 2·0 advertisements per day. Girls of all ethnicities were exposed to 30% more alcohol advertisements than boys.[259] Furthermore, existing inequities are reproduced by marketing to the next generation of consumers (eg, in the USA, African-American youth viewed approximately 50% or more adverts for unhealthy foods than did white youth of the same age).[260] Children in LMICs are also highly exposed: in a sample of 2423 5- and 6-year-olds in Brazil, China, India, Nigeria, and Pakistan, 68% could identify at least one cigarette brand logo, ranging from 50% in Russia to 86% in China.[261]

E-cigarettes are a new but worrying threat, particularly in HICs. Exposure to e-cigarette adverts was prevalent in US youth, who had medium-to-high exposure to e-cigarette adverts from the internet (38·6%), newspapers (29·6%), shops (53·2%), and TV (35·4%).[262] E-cigarette advertising is not regulated in the USA, where youth exposure to television e-cigarette advertisements, measured by target rating points, increased by 256% from 2011 to 2013,[263] with young adult exposure increasing by 321% over the same period. Adverts for these products in the USA reach more than 24 million young people.[264]

Additionally, new technologies are exacerbating and creating new threats to children that are not well understood. Gambling is a potentially large and unaddressed public health challenge for children.[264,265] The public health harms associated with gambling include anxiety and stress, disruption of work or study, and relationship conflict and breakdown. Moreover, children become socialised to gambling at an early age, with indications that exposure is associated with consumption intention.[266] The UK has 340 000 adult problem gamblers and 1·7 million more people suffering some harm—in a country where one in eight children aged 11–16 years follow a gambling company on social media.[267] In the UK, as in most countries, gambling adverts on TV sport events, which are accessible to children, are unregulated. In Australia children had detailed recall of sports betting advertisements and an extensive knowledge of sports betting products and terminology.[268]

Children's online exposure

Children's online exposure is nothing short of enormous. A review in the UK, published in 2018, showed that children aged 5–15 years, spend on average 2 h online on a weekday and 3 h per day at the weekend.[269] Children aged 11–16 years post on social media 26 times a day, adding up to tens of thousands of posts by age 18 years.[270] At the same time parents of children aged up to 13 years share an average of 100 photos and videos of their child each year.[271] Between 2010 and 2015 the global volume of data increased eight-times and by 2020 the introduction of new technologies will increase the volume 40-times.[272]

Online behaviour can bring both harm and benefits to children. Although some studies have found that social media use is not predictive of impaired mental health functioning,[273] social media is increasingly understood as creating or exacerbating risks around young people's self-esteem, wellbeing, and risky behaviours.[274–276] Social media can affect children's sleep, mental and physical health, and their social lives. In a systematic review of the relationship between internet use and self-harm and suicidal behaviour, online exposure was found to normalise self-harm, trigger abnormal behaviour and competition between users, or act as a source of contagion and harmful information for vulnerable individuals.[277] More commonly, children and young people develop so-called problematic use of the internet, a proposed umbrella term for a range of repetitive impairing behaviours,[278] including excessive and compulsive video gaming, compulsive sexual behaviour, bullying, gambling, and social networks use. The health and societal costs of problematic use of the internet across the lifespan are unknown, but they could be huge. Exposure to violent pornography is also a major concern and attempts to regulate access by age are often easily bypassed.

Vulnerable youth can also be targeted for radicalisation by militant groups, which occurs daily in many countries, across all income groups and security situations. Children are more easily intimidated and easier to control, physically and mentally, than adults. Children are also more inclined to show loyalty to authority figures.[279] Militant groups develop precise propaganda strategies to generate empathy and highlight the advantages of joining the group, which can include status and prestige, smart uniforms, and weapons. Social media platforms, including email, chat rooms, e-groups, message boards, video recordings, and applications are popular grooming and recruitment tools.[280] Much more research and attention is needed to protect children and young people from the negative effects social media can have on their risk-taking behaviours, mental health, and wellbeing.

However, the internet can bring great benefits through crisis support, reduction of social isolation, delivery of

therapy, and outreach. Young people use social media to communicate their distress, particularly to peers. Social media is a potentially accessible, inexpensive way to have conversations about mental health, including to promote health-seeking and reduce isolation.[281] Online friends can be an important source of social support for LGBT, queer or questioning, and intersex youth, and a growing amount of literature suggests that the internet can be a safe haven for some young people belonging to sexual minorities.[282] For families of children with disabilities and illnesses like cerebral palsy, social media can provide a platform for emotional support and forming connections, sharing information and advice, and learning about services,[283] but the quality of information is variable.[284] Interventions using artificial intelligence, such as chatbots, also have promise in engaging adolescents about health issues, such as obesity.[285] Adolescents in particular are avid users of technology for health, and can be reached through digital platforms with health messages and to participate in chat and support groups online. More research is required to understand ways to engage with them positively in this medium.[286]

Use of children's data and images by commerce

Online data has the potential to threaten a child's safety, development, and social interaction by normalising surveillance and increasing the risk of identity theft, fraud, and profiling. Children and young people are often the first to adopt new digital devices, services, and content, as such they are especially vulnerable, especially to data manipulation through non-transparent and biased algorithms (eg, based on race or ethnicity).

As a result, internet safety is a major concern, leading a small but growing number of countries to make it part of the school curriculum. Data collected online includes information given directly (eg, date of birth on a social media profile), data given unknowingly (eg, captured through web cookies or app-based location data), and data that is inferred (eg, based on algorithms and predictions analysed by companies). Data can also be collected through the internet of things, such as smart speakers, internet-connected toys, or baby cameras; and outside the home, from tracking watches, school databases, study and behaviour apps, biometric data in schools, digital personal health records, travel passes, and retail loyalty cards.[269]

Of course, data collection can have major benefits: general practitioners and hospitals can share data to enable early identification of patients, audit of services can improve accountability, analysis can prevent harm and promote positive health outcomes, and digital health and development records can expedite care. But governments and parents have major concerns, and many questions remain. Could data about a child's language development or educational performance play some role in their university application outcomes? Will parents' shopping habits affect the products and services their children are targeted with through advertising? Could personal health data impair access to insurance in future? And how safe is our data? Both public sector bodies and commercial organisations have failed to ensure privacy, transparency, security, and redress when handling children's data. These concerns frequently intersect (eg, when unregulated commercial activity around internet-based genetic testing erodes public trust in government programmes developed using more rigorous scientific methods).[287] Within the confines of government programmes, child centred-data raises both promising avenues and reasons to worry. For example, predictive risk modelling has been embraced both as a powerful tool for preventing and detecting child abuse, and criticised for individualising social problems and reifying oppressive frameworks of risk and abuse.[288] In the UK, a database created in 2004 to enhance child protection by improving information sharing between services was decommissioned in 2010, following criticisms by civil liberties groups that it was intrusive and that the data was not securely stored.

The European General Data Protection Regulation has attempted to tighten regulation on data protection and privacy, including for children. Article 5 states that "data must be processed lawfully, fairly and in a transparent manner"[289] and asks for special protection for children's data "for the purposes of marketing or creating personality or user profiles and the collection of personal data with regard to children when using services offered directly to the child."[289] The General Data Protection Regulation goes further to protect children's "right to be forgotten,"[289] requiring age-appropriate privacy notices and expressed consent for personal data to be used. However, national governments face the unenviable task of policing such regulation in a fast-moving field where technological innovation is constant.

Voluntary regulation and existing global frameworks are not sufficient

When seeking to protect children from harmful commercial exploitation, self-regulatory schemes have had a very small effect on marketing to children or in protecting use of their data. In Mexico, companies that had signed up for self-regulation focused 93% of their advertisements on unhealthy food and beverages.[290] In Canada companies promoted unhealthy foods and beverages at similar rates during programmes with high numbers of child viewers, whether or not they participated in the Canadian Children's Food and Beverage Advertising Initiative.[291] In New Zealand, 88% of unhealthy food advertisements were shown during children's peak viewing times, in contravention of a number of self-regulation agreements by industry.[292] In Australia, children's exposure to unhealthy fast-food advertising did not change following the introduction of self-regulation.[293] In Spain, non-compliance with the Spanish code of self-regulation of food and drinks advertising directed at

children under the age of 12 years has only increased between 2008 and 2012.[294] In Sri Lanka, of all food and beverage-related advertisements, 78% were child-focused, and of these 74% claimed health benefits, many of which were unsupported.[295] In the USA only 1·4% of all child-targeted food adverts met all aspects of Interagency Working Group on Foods Marketed to Children guidelines.[296] Additionally, alcohol brands popular with underage drinkers were more likely than others to advertise in magazines with high underage readerships, despite voluntary advertising industry guidelines to protect underage youth from high and disproportionate exposure to alcohol advertising.[297] Children in countries with weaker government regulation might be at greater risk of advert exposure: a 2008 report by the BBC suggested that British American Tobacco, London, UK violated its own voluntary international marketing standards in Nigeria, Malawi, and Mauritius.[298]

Current national schemes of regulation and engagement with commercial companies thus leave children highly exposed. Although global institutions have offered some guidance, and the EU has advanced some initiatives in this respect, shared principles are needed on good governance of relationships with the commercial sector for protecting the rights and wellbeing of children. As Woodrow and Press reported,[299] we must be wary of a so-called commercialised view of childhood, and acknowledge the responsibility of societies to protect children from profit-making at the expense of their wellbeing.

The CRC and associated Optional Protocols[300] provide standards against which agreements, services, and other actions might be measured for their effect on children and their rights, and a UNICEF[300] toolkit outlines steps businesses should take to ensure that their interactions with and influences on children do not adversely affect their welfare. Furthermore, global guidance is provided by the UN High Commissioner for Human Rights,[302] with additional guidance on Children's Rights and Business Principles.[303] These resources describe not only how commercial enterprises, including their suppliers, advertisers, marketers, and other associates should consider child labour, protection, safety, and the local environment in their activities, but also whether their activities, products, or services adversely affect children's wellbeing. The responsibilities of national governments regarding the relationship between the commercial sector and child wellbeing has also been emphasised by global authorities, with a General Comment issued under the CRC in 2013.[304]

Notwithstanding these standards and guidance, a small amount of evidence exists regarding businesses considering child wellbeing in their decisions and actions, and many enterprises consider it irrelevant or inimical to their activities.[305] Existing guidance is seen as soft and optional, with corporate behaviour dependent on "reputational accountability and the coercive strength of the web of accountability that is created through networks of organisations and overlapping and complementing soft law regulations."[306] Collins,[305] in an extensive mixed-method review of these issues, considers both the commercial and rights perspectives, and cites the former chair of the UN Committee on the Rights of the Child Jaap Doek who described the "insincere eloquence" of some corporate social responsibility activities, and the inseparability of issues of corporate behaviour and children's rights.

Given such considerations and rising concerns about the health effect of inappropriate marketing practices, the Independent Accountability Panel under the Every Woman Every Child initiative called for the adoption of a legally binding global convention to regulate the food and beverage industry in 2018.[307] The Independent Accountability Panel recommendations included specific mention of the International Code of Marketing of Breast-milk Substitutes (which is not a legally binding instrument), and the need to bring together the Code and other existing international standards on marketing for and to children and adolescents. However, the development and adoption of such a treaty would likely be a challenging process.

Initiating a political process to secure a legally binding instrument on marketing products to and for children

A legally binding instrument to effectively regulate commercial appeals to children would be a tangible and desirable product of the SDG era, even if this only covers part of the commercial harms to children, which also includes products marketed to adults (such as guns and ammunition and products containing chemicals harmful to children—such as bisphenols, phthalates, and lead paint), alongside a panoply of environmental harms that threaten life on this planet more generally.

Specifically, we propose adding an Optional Protocol to the CRC regarding commercial marketing and targeting of children, which would require national governments to prohibit or regulate the types of products that should not be marketed to or for children (including sugary beverages, unhealthy foods, alcohol, tobacco, e-cigarettes, gambling products, and breastmilk substitutes); regulate specific methods of marketing to children (via television shows, games, and social media used by children and youth, and sponsorship of youth activities); and control the gathering and exploitation of children's data and images for commercial purposes. Given the cross-border effects of commercial marketing, including through the internet and social media, and the multisectoral nature of the threat and needed response, an Optional Protocol to the CRC adopted by the UN General Assembly could address the transnational elements of the problem and simultaneously drive national action for legal protection.

A coalition of countries that have taken leadership in protecting children from commercial harms, supported by UN and civil society partners, could bring the

proposal for adding a protocol to the CRC to the UN General Assembly. Importantly, if such a protocol were to be adopted, establishment of a new monitoring mechanism would not be needed because the existing global oversight body under the UN Committee on the Rights of the Child would automatically monitor national implementation efforts. Having ratified the additional protocol, national governments would need to submit periodic reports on implementation of the provisions contained therein for review and scrutiny by the committee, with observations and recommendations made public. Regional bodies could be recruited to help steer implementation. National oversight could be initiated through government departments responsible for women's and children's development, commerce, health, education, and media and information, with additional independent monitoring by national human rights institutions and civil society partners.

Such a protocol could build upon the precautionary principle, introduced in environmental science in the 1990s in recognition of vulnerable groups, especially children. The principle holds that when an activity raises threats of harm to human health or the environment, precautionary measures should be taken to mitigate this action, even if cause-and-effect relationships are not fully established scientifically.[308] The precautionary principle has been widely used by environmental scientists and regulatory authorities,[310,311] but it has been insufficiently applied to protect children from commercial marketing—commercial entities can market products to children with little evidence that they do not pose a threat to their wellbeing. Although evidence is emerging on the harms of commercial sector marketing to children, the fast-paced nature of technological change means children are actively being harmed while the body of evidence grows.

One component of the precautionary principle is to shift the burden of proof to the proponents of the activity. This has been called reverse onus, when the burden of proof (ie, safety) or the analytical burden is shifted from the risk mitigator (ie, government regulators) to the risk generator (ie, industry).[310] The EU's Registrations, Evaluation, Authorisation, and Restriction of Chemicals regulation has adopted this approach to some extent. Given the conflicts between industry interests and public good objectives, many researchers have reported that a spectrum of risk exists.[311–313] These debates have led to guidance from UN committees on monitoring private sector policies, practices, and partnerships relating to the food industry[314] and global research consortia,[313] which could provide a framework for outlining a system of risk classification with respect to potential harms to children.

In addition, further work is needed to counter other harms to children, such as those outlined in the Framework Convention on Tobacco Control, efforts to reinforce the International Code on Marketing of Breast-milk Substitutes, unhealthy food advertising and sponsorship (reported by Swinburn and colleagues)[315] and fossil fuels, which go beyond the purview of this Commission. Experiences with regulating tobacco and sugar suggest that direct regulation of industries whose behaviour adversely effects children will be difficult.[316] Progress in tobacco control, including the adoption of the Framework Convention on Tobacco Control, was hard fought over decades, with corporate efforts to discredit the evidence linking tobacco consumption or exposure with ill health. Implementation of the tobacco framework was hampered by global conglomerates with enormous resources to fight regulation of tobacco product marketing and sales, and by country governments protecting local producers. Reports have emerged of similar efforts to distract lines of research or discredit scientific evidence of links between sugar consumption and non-communicable diseases by the sugar-sweetened beverage industry.[317] These efforts will likely be redoubled given increasing global calls for taxes on sugar, tobacco, and alcohol to reach the SDGs.[318] Further, implementation of such treaties might be slow to evolve because of challenges in domestic courts stemming from the interests of industries and corporations, which in some cases have acquired the same rights as people to fight government regulation.[319]

Such potential obstacles are all the greater given that many multinational corporations have resources larger than some national governments and they are willing to defend their presumed rights in global tribunals, using existing agreements, such as those developed by the World Trade Organization. Furthermore, country governments are often faced with competing incentives, such as promoting business and commercial enterprises, even those involving unhealthy products, in the interest of economic development. New international law on this topic would aid governments to apply and strengthen domestic legal frameworks, including constitutional law, in the interest of children's health and wellbeing. Notwithstanding its likely arduous gestation, an Optional Protocol to the CRC to protect children from commercial marketing would also attract many proponents, and would provide a strong precedent across other sectors for balancing public goods and commercial interests.

Meanwhile, indirect efforts that heighten public awareness of related risks (eg, banning advertising of or public communication on harmful products, or their consumption in public; taxation; and public advocacy or awareness-raising) have been successful in changing public opinion and corporate behaviour, and have survived corporate challenge in the courts. While any such treaty is being negotiated, global awareness of the rights of children to be protected against such influences must be raised through similar indirect efforts.

Summary

We reviewed the many potential and actual harms to children from commercial marketing, via traditional advertising and in the digital space, and proposed a

process for adopting an Optional Protocol to the CRC to provide a strong protective riposte. We now step back to examine the broader data and accountability landscape for children in the SDG era, and look at how to monitor, review, and act on data to achieve child health and wellbeing goals.

How to monitor, review, and act on SDG progress for children?

Compared with the Millennium Development Goals, the SDGs encompass a more comprehensive view of development, which poses greater challenges for the data and information required to make the best policy choices, track SDG progress, and ultimately, deliver on the targets of the global goals.[320] The data needs for children range from monitoring survival, intervention coverage, and disease prevalence to indicators related to growth, education, and wellbeing, including socioeconomic and environmental determinants of health.

Despite poor-quality systems for data collection, analysis, and information dissemination in most LMICs, the number of goals has doubled, from eight Millennium Development Goals to 17 SDGs, with 232 indicators and 169 targets. Reporting requires collation of hugely diverse data sources for social, political, economic, and environmental measures, and disaggregation of these to monitor equity (panel 9).

Addressing the data gap for children

Focused on leaving no one behind, the SDG agenda places the world's most vulnerable and marginalised people—including children—at the top of the global development agenda. UNICEF categorises the child-related indicators around five dimensions of children's rights: survive and thrive; learning; protection from violence and exploitation; safe and clean environment; and a fair chance in life;[321] we use the same five categories to describe indicators. The roadmap for achieving the SDGs for women's, children's, and adolescent's health is laid out in the Global Strategy for Women's, Children's and Adolescents' Health (2016–2030).[17] The strategy focuses on three main domains: survive (end preventable deaths), thrive (ensure health and wellbeing), and transform (expand enabling environments).[17]

Of the 232 SDG indicators, 47 are directly relevant to child health and wellbeing (appendix pp 5–18). Indicators have been classified into three tiers by the Inter-Agency and Expert Group on SDG Indicators based on the availability of data and standardised methodologies for assessment. Of the 47 child-related indicators, 17 are designated tier 1, 21 tier 2, and 9 tier 3 (figure 7), suggesting that 30 (64%) of the child-related indicators are not regularly produced by countries, or that definitions and standards for measurement have not been developed. Even in instances where data are available, there might be too few datapoints to establish a trend or calculate projections towards targets.

Panel 9: Monitoring, reviewing, and acting on the Sustainable Development Goals (SDGs)—key messages

- Data needs for measuring and monitoring progress towards child health and wellbeing targets are high, but most countries do not regularly collect comparable data for a large proportion of child-related SDG indicators
- Because disaggregation is key to make sure no one is left behind, greater investments are needed to strengthen the systems for the collection and use of routine and administratively collected data to complement reporting on equity, for which household surveys are the main source
- Child flourishing can be measured for all countries using indicators that are reported, but a complete picture requires accounting for sustainability and the health of our planet, as in our proposed child flourishing and futures profile
- Data openness and citizen participation, including youth-led initiatives, can harness new energy and capacities to overcome the barriers to collecting data towards SDG progress, as well as fulfilling rights to participation, co-ownership, and community responsibility

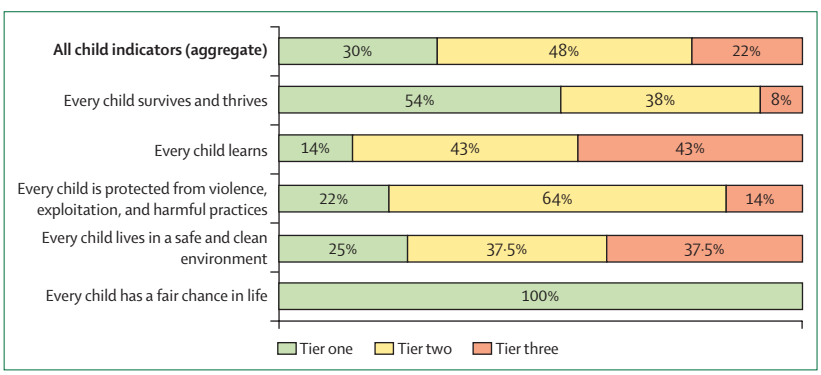


***Figure 7*: Child-related Sustainable Development Goals indicators by tier status**
Tier one=indicator is conceptually clear, has an internationally established methodology and available standards, and data are regularly produced by countries for at least 50% of countries and of the population in every region where the indicator is relevant. Tier two=indicator is conceptually clear, and has internationally established methodology available standards, but data are not regularly produced by most countries. Tier three=no internationally established methodology or standard are available for the indicator, but methodology and standards are being (or will be) developed and tested.

The indicators that are most regularly reported by countries are related to poverty and health (especially mortality and health care intervention coverage). The newer and least well established indicators on thrive and transform (including climate, sustainable cities, gender equality, and quality education) have large data gaps, these gaps also exist for the survive indicators for children older than 5 years.

The availability of data on child-related SDG indicators varies between LICs, MICs, and HICs (figure 8). Data availability in LICs is highest in Senegal and lowest in Comoros. Of the MICs, Mexico has reported on the greatest number of child-related indicators and Kosovo the least, and of the HICs, Norway has reported on the

greatest number of indicators. However, no country has reported on more than 70% of the child-related SDG indicators. For many HICs the low number of indicators reported on is because they are already meeting the targets. Analysing the amount of available data for each indicator within the five domains of children's rights across all country income groups (figure 9) shows that few, if any, data are available for indicators on education, violence and exploitation, and safe environment.

SDG indicators take a life course approach and include measures of health and wellbeing from preconception to the end of adolescence, while acknowledging there are intergenerational effects on health and wellbeing (figure 1). However, the indicators vary in terms of quality and reliability. Birth and infancy indicators have better data availability than late childhood and adolescence indicators. For example, very few LMICs report data on indicators related to violence (physical, sexual, and psychological) for adolescent women (indicator 5.2.1 and 5.2.2). Information on the prevalence of child marriage (5.3.1), child labour (8.7.1), literacy and numeracy (4.1.1), and information communication technology literacy (4.4.1) are also infrequently reported (appendix pp 5–18 for a summary of each child-related SDG indicator).

Data on children are derived from multiple sources, including household surveys, routine facility reporting, facility assessments, and administrative data (such as health workforce and financing data, civil registration, and vital statistics). Facility reporting systems are an important source of data for output and service utilisation data, but quality can be problematic.[322] 33 of the 47 child-related indicators are dependent on national household surveys as their primary data source. However, household data, mainly obtained through the implementation of Demographic and Health Surveys and Multiple Indicator Cluster Surveys, cannot meet the demand for annual monitoring because they are done every 3–5 years, or for subnational data, especially at the district level, because most national surveys are designed to provide only regional estimates.[323] Furthermore, lag time can be more than a year between data collection and reporting, and even longer for datasets to be available for secondary analysis.

The global SDG indicator framework has an overarching principle of data disaggregation for income, gender, age, race, ethnicity, migratory status, disability, and geographic location.[324] Although SDG indicators that are compiled from household survey data can be disaggregated (eg, gender and geographic location) population samples are often too small to obtain reliable subgroup estimates.[325] Data for global reports on national and regional estimates are often too sparse to be disaggregated; in other cases, analyses are restricted to strata with sufficient data, such as rural or urban location and gender. Some stratifications might be sensitive to collect in certain contexts, such as for race, ethnicity, religion, or sexual orientation.

Disaggregation is essential to make existing gradients objective and tangible. To view the situation of children through national averages risks masking their realities, especially when attempting to pinpoint the inequities and violations of rights that affect them. Disaggregation must be done sensitively, for example to avoid ignoring transgender and non-binary people when classifying by sex. However, children with disabilities, refugee and migrant children, children belonging to indigenous groups, or other ethnic or racial minorities, among others, are at risk of being left behind if they remain invisible in national monitoring processes. Only 18% of countries have reported on indicator 4.a.1, which measures the proportion of schools with access to adapted infrastructure and materials for students with disabilities, and several of those countries report that no schools have suitable adaptions. The Washington

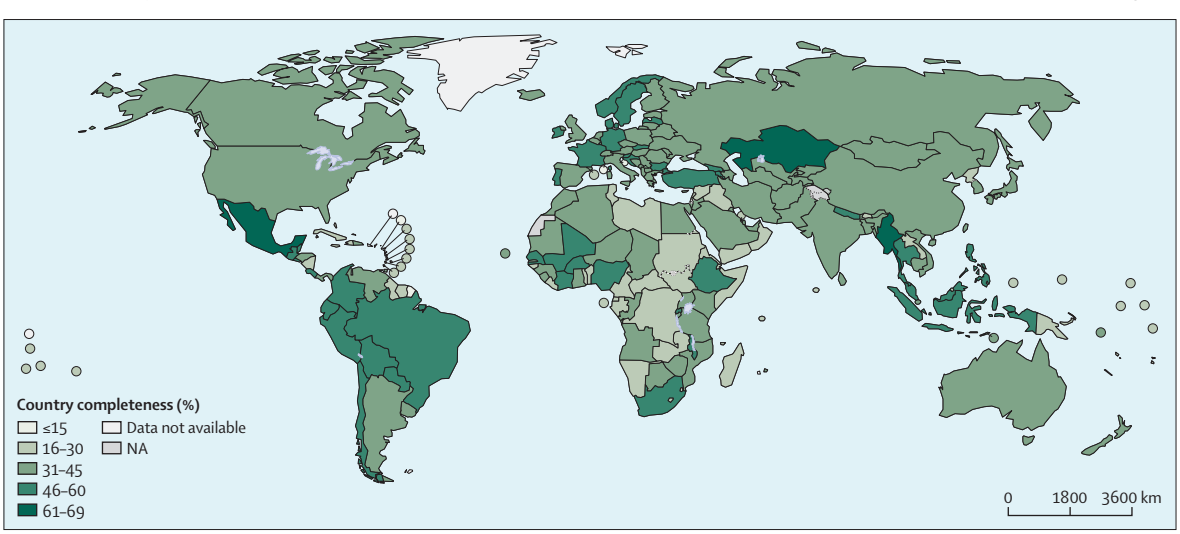


Figure 8: **Availability of data on child-related Sustainable Development Goals indicators by country**
The figure shows the percentage of child-relevant SDG indicators with at least one datapoint reported since 2015.

Group on Disability Statistics, a UN-sponsored group, and UNICEF, in partnership with Disabled People's Organizations, have developed a new way of gathering information on child disability. New questions to identify children with disability have been included in UNICEF's Multiple Indicator Cluster Survey and are being piloted in around 40 LMICs.[321]

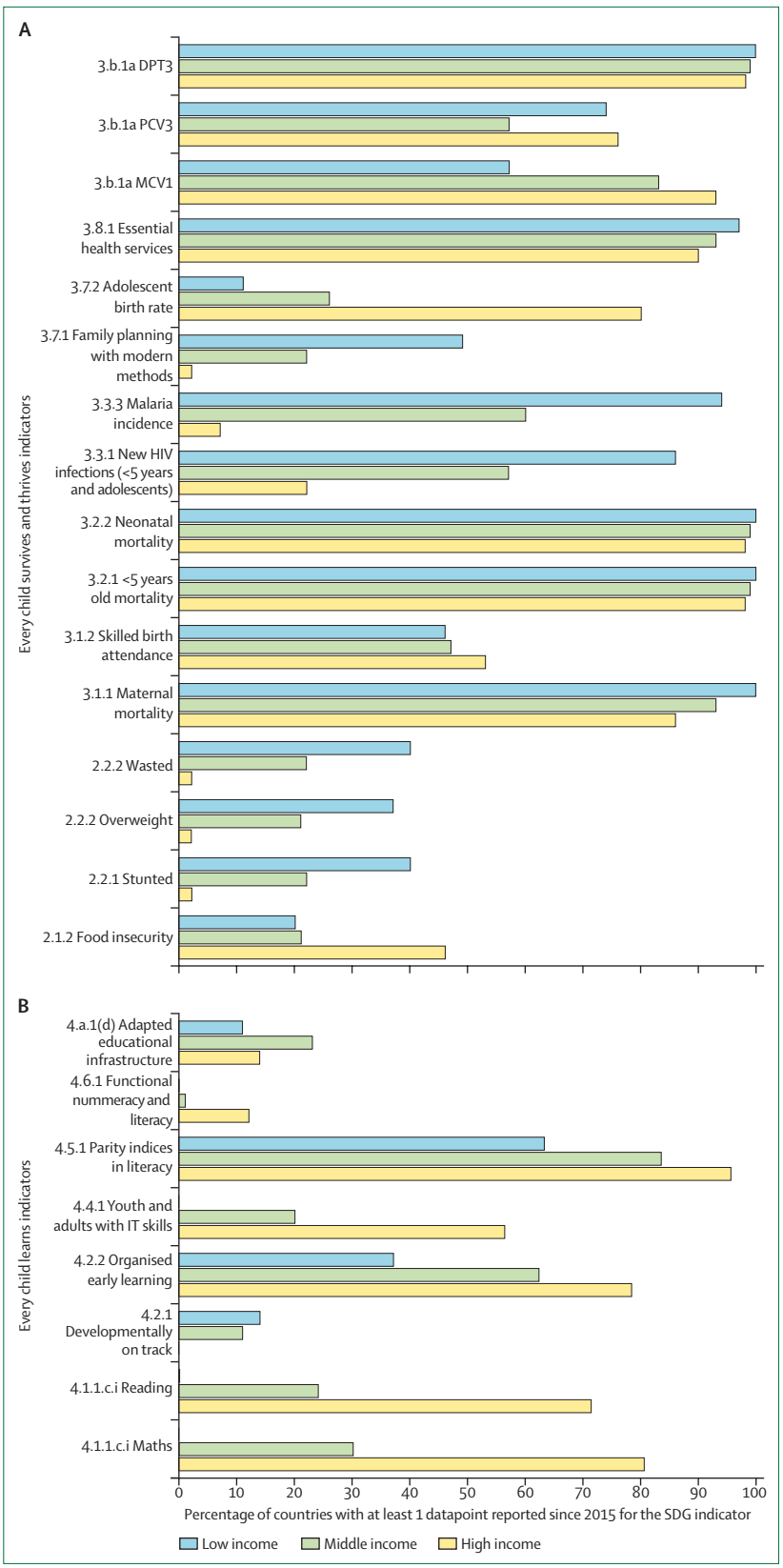
How to get good-quality data

In 2016, 22 countries did national SDG reviews and submitted reports to the UN High-level Political Forum on Sustainable Development. In 2017, the number nearly doubled to 43 countries. Many LMICs struggled to present national and disaggregated statistics for most child-related SDG indicators (figures 8 and 9). The reality of national planning and budgeting processes means that interventions and outcomes for which data are scarce do not get prioritised.

For many LMICs the data burden is far too onerous. Many government departments and national statistical offices face capacity and financial constraints, making data collection and completion of regular surveys difficult.[323] Consequently, reports do not give a comprehensive picture of child wellbeing.[326] Moreover, given the number of informal dwellers, surveys in urban locations are far more difficult to do than surveys in relatively stable rural communities.

Targeted investments are required to strengthen national information systems within and across sectors, particularly in countries with weak information systems. UN agencies, such as WHO and UNICEF, work with academic institutions and carry out country consultations to produce global health estimates on child health and wellbeing using complex modelling processes. In 2018, WHO announced a collaboration with the Institute of Health Metrics and Evaluation to produce the Global Burden of Disease estimates. Funding agencies, especially the Bill & Melinda Gates Foundation, are making major investments in global health estimation. These efforts are important for regional and country comparisons and for global advocacy purposes. Nonetheless, the estimates can give a false impression of an abundance of data.[327] The reality is that most data on children, usually from household surveys, are out of date or subject to long recall periods. Analysis and presentation are rarely helpful to authorities for planning subnational action and strategies.[327]

Large data gaps can be filled with greater involvement of citizens and communities in monitoring progress and enabling local action and accountability.[328] Furthermore, we must focus on improving the collection of data for populations that are hardest to reach or for which little data exists, such as children with disabilities. Strengthening of national information systems is a priority that has been largely ignored. Little investment has been made into building capacity for collection and use of information and for enhancing accountability locally.



(Figure 9 continues on next page)

This is not just a technical issue, but a rights-based public policy imperative deriving from the principle of information as a global public good.

Applying a life course approach to monitoring requires the integration of data systems for mothers and children.

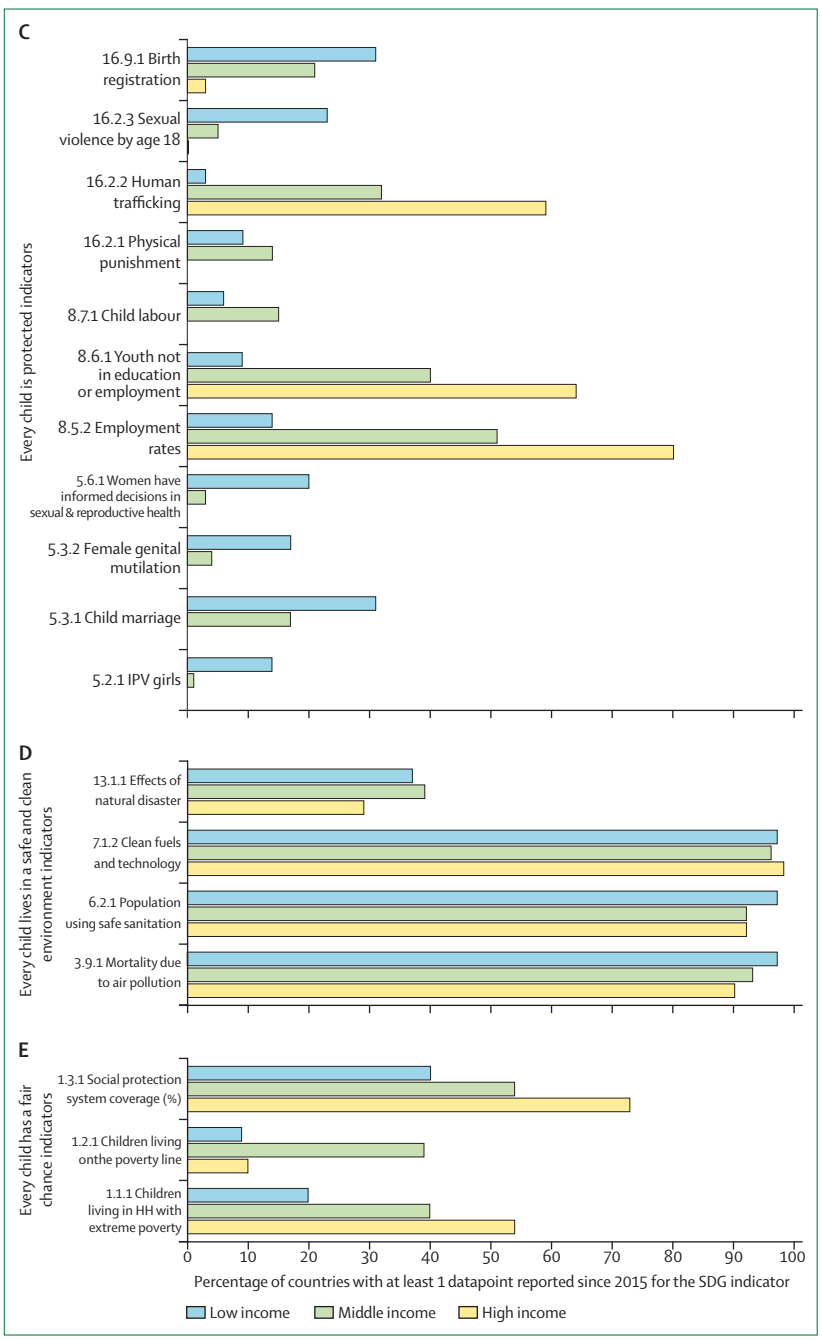


***Figure 9*: Completeness of child-related SDG indicators data for each of the five each domains of children's rights (at least one datapoint since 2015): every child survives and thrives (A); every child learns (B); every child is protected from violence, exploitation, and harmful practices (C); every child lives in a safe environment (D); every child has a fair chance in life (E) from low-income, middle-income and high-income counties**

IT=information technology. SDG=Sustainable Development Goal. IPV=intimate partner violence. HH=household. See appendix pp 5–18 for full indicator definitions.

In the siloed global aid architecture used nowadays, integrating systems is difficult to achieve with separate programme-specific monitoring and funding streams[329] (eg, for newborn health or family planning), which compete within a narrow space for attention and funding.[164,236,239]

Some SDG indicators could be captured through national civil registration and vital statistics systems or routine information systems (eg, immunisation coverage and birth registration), which is why LMICs require support to strengthen their health management information systems. Brazil is one example of a MIC that has invested in strengthening its routine health information system as part of a process of broader health system reform. This included the establishment of the Sistema Único de Saúde Hospital Information System, the Mortality Information System and the Live Births Information System, which was launched in 1990 to provide standardised data collection procedures at all hospitals; by 2002 the Live Births Information System included data for 86% of all livebirths.[322] The data from these systems is brought together using interinstitutional coordination to build and standardise indicators, and disseminate basic data, indicators, and health status assessments in an organised manner through the Interagency Health Information Network.[330] Brazil has not undertaken a Demographic and Health Survey since 1996, opting instead to undertake their own nationally planned and implemented surveys that enable the country to report on the majority of child related SDG indicators. As more MICs shift away from Demographic and Health Surveys to independent national surveys, a need exists to ensure that such national surveys adopt internationally-standardised questionnaires and measurement protocols, so that their results can be compared with those of other countries.

The open source district health information system 2[331] is the world's largest health management information systems platform and is operational in 67 LMICs, and it is also used in some countries (eg, Zambia) to capture education data. Very few indicators (3 of 47) use data from routine sources; improving these routine systems will be a long process, and it is absolutely essential to invest in doing so. The district health information system captures data on services at facilities, from primary to tertiary level, and in many countries also includes activities by community health workers and environmental health officers. The district health information system is an important source of information for SDG monitoring, but it does not contribute to reporting on many SDG indicators for several reasons. First, the district health information system only provides information on individuals who access care; therefore, they are not representative of the entire population, especially where health care utilisation is low; second, data from the private sector is usually not included; third, district health information system data is owned by governments and access to the information

for agencies compiling global monitoring databases requires negotiations around data ownership; and finally, the quality of routinely collected health information is often poor.s

Despite these challenges, district health information system 2 could monitor health service coverage indicators in settings with high utilisation of services or reliable information from censuses on population denominators, and for local monitoring via the development of automated score cards for community-facility monitoring activities.

Again, many SDG indicators cannot be monitored through routine information systems that only include citizens who attend a health facility or a school. These data are not nationally representative because they do not capture those citizens who do not attend these facilities. Indicators measuring essential issues such as nutritional status, intimate partner violence, child poverty, and clean fuel access will continue to require household surveys.[325] A balance is needed between reducing the existing reliance on surveys and overloading routine systems, on the basis of a holistic assessment of each country's policies around data and information systems.

A child flourishing and futures profile: a new way to understand country progress

The ultimate aim of the SDGs is to ensure that all children are able to flourish and lead happy, meaningful lives, now and in the future. If countries are to create national and subnational accountability towards the SDGs, particularly regarding child health and wellbeing, they need a summary index of country performance for planning and cross-country comparison. We constructed a new national profile to measure the foundational conditions for children aged 0–18 years to survive and thrive today (table), and act as a proxy measure of future environmental threats to children based on projected greenhouse gas emissions excess in 2030. These two measures of child flourishing and environmental sustainability threats combine to produce our child flourishing and futures profile (figure 10).

Constructing the flourishing index from the SDG indicators

Our flourishing index was constructed first by comparing dimensions proposed by major conceptual frameworks for child wellbeing and human flourishing in HICs, MICs, and LICs, namely UNICEF's Five Dimensions of Children's Rights in the SDG Era;[321] the UN Global Strategy for Women and Children's Health;[17] Martha Nussbaum's basic capabilities for human flourishing;[332] VanderWeele's seven dimensions of human flourishing;[333] the systematic review of indicators of child wellbeing by Pollard and Lee;[334] and framework of positive child wellbeing by Lippman and colleagues.[335] We selected indicators—primarily SDG indicators—and aggregation methods to match those domains.

	Rank	Flourishing*	Surviving	Thriving	World Bank classification
Central African Republic	180	0·06	0·01	0·38	Low income
Chad	179	0·10	0·03	0·28	Low income
Somalia	178	0·12	0·03	0·40	Low income
Niger	177	0·12	0·06	0·26	Low income
Mali	176	0·14	0·06	0·33	Low income
Guinea	175	0·17	0·08	0·35	Low income
Nigeria	174	0·18	0·08	0·38	Lower-middle income
South Sudan	173	0·19	0·11	0·33	Low income
Sierra Leone	172	0·22	0·13	0·35	Low income
Afghanistan	171	0·22	0·13	0·38	Low income
Mozambique	170	0·24	0·16	0·38	Low income
Liberia	169	0·25	0·16	0·40	Low income
Benin	168	0·25	0·18	0·35	Low income
Democratic Republic of the Congo	167	0·26	0·16	0·43	Low income
Guinea-Bissau	166	0·26	0·16	0·43	Low income
Madagascar	165	0·27	0·18	0·40	Low income
Malawi	164	0·28	0·21	0·38	Low income
Burkina Faso	163	0·29	0·21	0·40	Low income
Côte d'Ivoire	162	0·29	0·20	0·43	Lower-middle income
Angola	161	0·29	0·20	0·43	Lower-middle income
Lesotho	160	0·30	0·21	0·43	Lower-middle income
Papua New Guinea	159	0·30	0·28	0·33	Lower-middle income
Yemen	158	0·31	0·25	0·38	Low income
Cameroon	157	0·32	0·23	0·45	Lower-middle income
Burundi	156	0·32	0·21	0·50	Low income
Togo	155	0·32	0·23	0·45	Low income
Mauritania	154	0·32	0·28	0·38	Lower-middle income
Ethiopia	153	0·33	0·30	0·35	Low income
Uganda	152	0·33	0·25	0·43	Low income
Haiti	151	0·35	0·25	0·48	Low income
Congo	150	0·35	0·28	0·45	Lower-middle income
Sudan	149	0·36	0·30	0·43	Lower-middle income
Zambia	148	0·36	0·30	0·43	Lower-middle income
Eritrea	147	0·37	0·30	0·45	Low income
Zimbabwe	146	0·37	0·33	0·43	Low income
Tanzania	145	0·37	0·33	0·43	Low income
Nepal	144	0·38	0·35	0·40	Low income
Bangladesh	143	0·38	0·40	0·35	Lower-middle income
eSwatini	142	0·38	0·30	0·48	Lower-middle income
Comoros	141	0·39	0·35	0·43	Low income
Pakistan	140	0·39	0·35	0·43	Lower-middle income
The Gambia	139	0·39	0·35	0·43	Low income
Kenya	138	0·39	0·30	0·50	Lower-middle income
Laos	137	0·40	0·30	0·53	Lower-middle income
Senegal	136	0·40	0·35	0·45	Low income
Timor-Leste	135	0·43	0·33	0·58	Lower-middle income
Equatorial Guinea	134	0·43	0·38	0·50	Upper-middle income
Ghana	133	0·43	0·38	0·50	Lower-middle income
Vanuatu	132	0·44	0·43	0·45	Lower-middle income
India	131	0·44	0·45	0·43	Lower-middle income
Rwanda	130	0·45	0·38	0·53	Low income
Solomon Islands	129	0·45	0·50	0·40	Lower-middle income

(Table continues on next page)

	Rank	Flourishing*	Surviving	Thriving	World Bank classification
(Continued from previous page)					
Guatemala	128	0·45	0·40	0·50	Upper-middle income
South Africa	127	0·45	0·40	0·50	Upper-middle income
Namibia	126	0·46	0·43	0·50	Upper-middle income
São Tomé and Príncipe	125	0·46	0·48	0·45	Lower-middle income
Gabon	124	0·47	0·40	0·55	Upper-middle income
Djibouti	123	0·47	0·43	0·53	Lower-middle income
Kiribati	122	0·47	0·53	0·43	Lower-middle income
Iraq	121	0·51	0·53	0·50	Upper-middle income
Myanmar	120	0·53	0·43	0·65	Lower-middle income
Suriname	119	0·54	0·53	0·55	Upper-middle income
Bolivia	118	0·54	0·45	0·65	Lower-middle income
Indonesia	117	0·54	0·48	0·63	Lower-middle income
Guyana	116	0·55	0·58	0·53	Upper-middle income
Dominican Republic	115	0·55	0·55	0·55	Upper-middle income
Cambodia	114	0·55	0·58	0·53	Lower-middle income
Bhutan	113	0·55	0·55	0·55	Lower-middle income
North Korea	112	0·55	0·45	0·68	Low income
Honduras	111	0·56	0·60	0·53	Lower-middle income
Philippines	110	0·56	0·55	0·58	Lower-middle income
Cape Verde	109	0·58	0·65	0·53	Lower-middle income
Ecuador	108	0·60	0·68	0·53	Upper-middle income
Venezuela	107	0·60	0·60	0·60	Upper-middle income
Botswana	106	0·60	0·60	0·60	Upper-middle income
Morocco	105	0·61	0·68	0·55	Lower-middle income
El Salvador	104	0·61	0·68	0·55	Lower-middle income
Egypt	103	0·61	0·63	0·60	Lower-middle income
Panama	102	0·62	0·60	0·65	High income
Nicaragua	101	0·62	0·65	0·60	Lower-middle income
Paraguay	100	0·64	0·60	0·68	Upper-middle income
Samoa	99	0·64	0·63	0·65	Upper-middle income
Tajikistan	98	0·65	0·63	0·68	Low income
Peru	97	0·65	0·65	0·65	Upper-middle income
Kyrgyzstan	96	0·66	0·58	0·75	Lower-middle income
Saint Vincent and the Grenadines	95	0·66	0·73	0·60	Upper-middle income
Belize	94	0·66	0·70	0·63	Upper-middle income
Fiji	93	0·66	0·68	0·65	Upper-middle income
Jamaica	92	0·66	0·68	0·65	Upper-middle income
Ukraine	91	0·66	0·68	0·65	Lower-middle income
Brazil	90	0·68	0·68	0·68	Upper-middle income
Seychelles	89	0·68	0·70	0·65	High income
Mexico	88	0·68	0·68	0·68	Upper-middle income
Tonga	87	0·68	0·63	0·75	Upper-middle income
Argentina	86	0·68	0·75	0·63	High income
Algeria	85	0·69	0·63	0·75	Upper-middle income
Mongolia	84	0·70	0·73	0·68	Lower-middle income
Saint Lucia	83	0·70	0·68	0·73	Upper-middle income
Colombia	82	0·70	0·73	0·68	Upper-middle income
The Bahamas	81	0·70	0·70	0·70	High income
Romania	80	0·71	0·65	0·78	Upper-middle income
Russia	79	0·71	0·78	0·65	Upper-middle income
Palestine†	78	0·71	0·75	0·68	Lower-middle income

(Table continues on next page)

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For Surviving, we selected maternal survival, survival in children younger than 5 years old, suicide, access to maternal and child health services, basic hygiene and sanitation, and lack of extreme poverty. For Thriving, the domains were educational achievement, growth and nutrition, reproductive freedom, and protection from violence. Each domain is measured by one or two key trace indicators. Good availability of data for most countries was an important factor in indicator selection, as was the need to shine a spotlight on issues including violence against women, child marriage, stunting, or educational achievement. Further details of index construction and scoring as well as individual indicator values by country are available in the appendix pp 19–66.

Briefly, surviving and thriving indicators comprise the two main dimensions of our flourishing index (we also use school education, which is a transform indicator under the UN Global Strategy). Scores for surviving and thriving are calculated separately after categorising each indicator and taking an arithmetic mean weighting each indicator equally within each domain and each domain equally within each dimension. The scores for each dimension are combined into an overall score using a geometric mean. An overall score close to 0 indicates very poor, with 0·25 indicating poor, 0·50 neither poor nor adequate, 0·75 adequate, and 1·00 good flourishing.

Scores and ranks were calculated for 180 individual countries with available data (table). At the higher end of the scale are HICs such as Norway, South Korea, and the Netherlands that typically satisfy the basic conditions for child survival, but still have room for improvement on child thriving. At the lower end of the scale are LICs, such as Central African Republic, Chad, and Somalia, that perform poorly on both child survival and thriving; generally, these countries perform worse on survival than thriving. Countries in the middle of the ranking include a mixture of income levels, such as Myanmar (lower-middle income, 120th), Brazil (upper-middle income, 90th), and Turkey (upper-middle income, 60th). In creating this index, we had to contend with large gaps in data availability with respect to indicators of child development, protection, and wellbeing. Many indicator values, such as maternal mortality or injuries, were drawn from heavily modelled data. This poses well known problems because the validity of modelled estimates depends on a combination of the validity of model assumptions and model robustness to deviations from its assumptions.[336,337]

In some instances, neither modelled nor raw data were available. Indicators on opportunity for participation and voice in local, national, and international affairs are also largely absent from the SDGs. These domains are core elements of a flourishing life across multiple conceptual frameworks.[332–334] Indicators of adolescent happiness, life satisfaction, and positive peer relationships are missing, and indicators for practical reason, meaning, purpose, and autonomy are only represented for girls within

indicators of female empowerment. Measuring these constructs in children is complex because of their subjective and context-specific nature. Collecting information and capturing the voices and experiences of children is also difficult; parents or caregivers are often asked to provide information about their children, but this might introduce bias because of long recall periods[338] or social acceptability.[339] Nonetheless, the global medical community has called for indicators of people's participation in health systems to be included in the next set of SDGs.[340]

Furthermore, current population-based measures of child development rely predominantly on proxy measures, such as stunting and poverty. Accurate assessment of child development is needed to monitor developmental progress from birth through to school entry.[341] Data on the proportion of children younger than 5 years who are developmentally on track with regard to health, learning, and psychosocial wellbeing are available for 66 countries, but this data currently excludes many LICs and HICs.[342] Universal population based measures designed to quantify child development are urgently needed, particularly for the youngest children. New tools for measuring early child development in children younger than 3 years old are under development (panel 10).

Because of data limitations, we envision our child flourishing index as a first step in the process of raising awareness regarding the need to measure and promote conditions fundamental to child wellbeing. Our index is primarily an illustrative tool for showing how SDG indicators can be used to construct a measure of child flourishing at a national level. The index might constitute a base from which more comprehensive indices can be developed as the depth and breadth of global monitoring indicators expands. In the future, countries developing strong subnational information systems might apply our index at district levels.

A proxy sustainability index for the future

Promoting today's national conditions for children to survive and thrive must not come at the cost of eroding future global conditions for children's ability to flourish. Under widely used business-as-usual scenarios, there is a 93% chance that global warming will exceed 4°C by the year 2100.[343] This would have devastating health consequences due to disruption of water and ecosystems, rising ocean levels, inundation of coastal cities and small island nations, increased mortality from heatwaves, proliferation of vector-borne disease, and a crisis of malnutrition because of disruption to food production systems.[3]

Both the 2015 Paris agreement and the Intergovernmental Panel on Climate Change have called on governments to restrict warming to below 1·5°C.[344] Achieving this will require substantial changes to global economic, political, and social systems.[344] Under realistic assumptions about possible trajectories towards

	Rank	Flourishing*	Surviving	Thriving	World Bank classification
(Continued from previous page)					
Azerbaijan	77	0·71	0·73	0·70	Upper-middle income
Georgia	76	0·71	0·70	0·73	Lower-middle income
Costa Rica	75	0·72	0·80	0·65	Upper-middle income
Libya	74	0·72	0·75	0·70	Upper-middle income
Lebanon	73	0·73	0·73	0·73	Upper-middle income
Maldives	72	0·73	0·80	0·68	Upper-middle income
Uzbekistan	71	0·74	0·70	0·78	Lower-middle income
Grenada	70	0·74	0·78	0·70	Upper-middle income
Albania	69	0·74	0·75	0·73	Upper-middle income
Sri Lanka	68	0·74	0·88	0·63	Lower-middle income
Mauritius	67	0·74	0·85	0·65	Upper-middle income
Uruguay	66	0·74	0·85	0·65	High income
Trinidad and Tobago	65	0·75	0·83	0·68	High income
Thailand	64	0·75	0·83	0·68	Upper-middle income
Iran	63	0·75	0·80	0·70	Upper-middle income
Jordan	62	0·75	0·80	0·70	Upper-middle income
Oman	61	0·75	0·80	0·70	High income
Turkey	60	0·75	0·78	0·73	Upper-middle income
Kazakhstan	59	0·75	0·78	0·73	Upper-middle income
Vietnam	58	0·75	0·73	0·78	Lower-middle income
Tunisia	57	0·75	0·73	0·78	Lower-middle income
Armenia	56	0·75	0·73	0·78	Upper-middle income
Moldova	55	0·75	0·73	0·78	Lower-middle income
Qatar	54	0·76	0·83	0·70	High income
Chile	53	0·76	0·83	0·70	High income
Turkmenistan	52	0·76	0·78	0·75	Upper-middle income
Barbados	51	0·76	0·78	0·75	High income
Antigua and Barbuda	50	0·76	0·78	0·75	High income
United Arab Emirates	49	0·78	0·90	0·68	High income
Serbia	48	0·79	0·75	0·83	Upper-middle income
Bahrain	47	0·79	0·90	0·70	High income
Cuba	46	0·80	0·83	0·78	Upper-middle income
Bulgaria	45	0·80	0·80	0·80	Upper-middle income
Malaysia	44	0·81	0·90	0·73	Upper-middle income
China	43	0·81	0·80	0·83	Upper-middle income
Kuwait	42	0·82	0·88	0·78	High income
Lithuania	41	0·82	0·85	0·80	High income
North Macedonia	40	0·83	0·83	0·83	Upper-middle income
USA	39	0·84	0·88	0·80	High income
Bosnia and Herzegovina	38	0·84	0·85	0·83	Upper-middle income
Latvia	37	0·84	0·83	0·85	High income
Saudi Arabia	36	0·85	0·93	0·78	High income
Belarus	35	0·85	0·90	0·80	Upper-middle income
Montenegro	34	0·85	0·88	0·83	Upper-middle income
Poland	33	0·85	0·85	0·85	High income
New Zealand	32	0·86	0·95	0·78	High income
Greece	31	0·86	0·93	0·80	High income
Slovakia	30	0·87	0·90	0·85	High income
Hungary	29	0·88	0·88	0·88	High income
Croatia	28	0·88	0·88	0·88	High income
Estonia	27	0·88	0·88	0·88	High income

(Table continues on next page)

	Rank	Flourishing*	Surviving	Thriving	World Bank classification
(Continued from previous page)					
Italy	26	0·89	0·93	0·85	High income
Slovenia	25	0·89	0·88	0·90	High income
Israel	24	0·90	0·98	0·83	High income
Cyprus	23	0·90	0·98	0·83	High income
Portugal	22	0·90	0·98	0·83	High income
Canada	21	0·90	0·95	0·85	High income
Australia	20	0·90	0·95	0·85	High income
Austria	19	0·90	0·95	0·85	High income
Malta	18	0·91	1·00	0·83	High income
Spain	17	0·91	1·00	0·83	High income
Finland	16	0·91	0·98	0·85	High income
Switzerland	15	0·92	1·00	0·85	High income
Germany	14	0·92	1·00	0·85	High income
Sweden	13	0·92	1·00	0·85	High income
Singapore	12	0·92	1·00	0·85	High income
Luxembourg	11	0·92	1·00	0·85	High income
UK	10	0·92	0·98	0·88	High income
Iceland	9	0·92	0·98	0·88	High income
Belgium	8	0·94	1·00	0·88	High income
Japan	7	0·94	1·00	0·88	High income
Denmark	6	0·94	0·98	0·90	High income
Ireland	5	0·95	1·00	0·90	High income
France	4	0·95	1·00	0·90	High income
Netherlands	3	0·95	1·00	0·90	High income
South Korea	2	0·95	1·00	0·90	High income
Norway	1	0·95	1·00	0·90	High income

*Flourishing is the geometric mean of Surviving and Thriving. An overall score close to 0 indicates very poor, with 0·25 indicating poor, 0·50 neither poor nor adequate, 0·75 adequate, and 1·00 good flourishing.
†State of Palestine/occupied Palestinian territory, including east Jerusalem.

Table: **Child flourishing index rankings**

sustainable greenhouse gas emissions—so-called shared socioeconomic pathways[344]—models predict that global carbon emissions need to be reduced from 39·7 gigatonnes to 22·8 gigatonnes per year by 2030[347] to maintain even a 66% chance of keeping global warming below 1·5°C.

A predicted world population of 8·1 billion by 2030[347] corresponds to a target of 2·7 tonnes of CO_2 emitted per capita by 2030 after adjusting for bunker fuels used aboard vessels. This can be considered a minimum target for high-emission countries because it allocates equal per capita emissions to all countries irrespective of their historical role in emitting carbon. Using data from the Global Carbon Atlas,[348] we can create a Sustainability Rank that ranks countries on excess carbon emissions compared with the 2030 target. This provides a convenient and available proxy for a country's contribution to sustainability in future.

Although many HICs rank extremely highly on the flourishing (survive and thrive) index; they are near the bottom in terms of performance on contributions to global ecological sustainability, and vice versa for LICs (figure 11). For example, Norway, South Korea, and the Netherlands are ranked number 1st, 2nd, and 3rd on current child flourishing, but these countries are 156th (Norway), 166th (South Korea), and 160th (the Netherlands) on global sustainability list, all of them with per capita carbon emissions more than 210% higher than the sustainability starget for 2030. Therefore, the two country ranks provide us with our child flourishing and futures profile, a combination of a country's achievement on surviving and thriving today, with the damage they might cause through greenhouse gas emissions to children in future.

A focus on equity

Equity is essential to ensure that efforts to promote children's present and future flourishing truly leave no one behind. The child flourishing and futures profile paints a picture of differences in achievement between countries. However, equity within countries across multiple axes, including geographical, social, ethnic, gender, and indigenous versus non-indigenous populations, is just as crucial. But data on these inequities is often scarce, meaning that within-country differences are often obscured, even though these often dwarf inter-country differences.

Equity data on child health and nutrition indicators is primarily available for LMICs, but data on economic inequality using the Gini coefficient is available for most countries (appendix pp 67–71). Plotting countries by their income-based Gini coefficient (a more appropriate measure of inequality than consumption-based Gini coefficient) against their child flourishing index score shows that, generally speaking, poorer countries with lower child flourishing scores tend to have greater economic inequality (figure 12). However, exceptions exist: the USA is a HIC that ranks as the 11th most unequal country in the world (among countries for which we have data on income inequality). Moreover, the child flourishing rank of the USA (39th) is also poor compared with many other HICs, and even some MICs.

Data and information for children at country and local level

A framework for action and feedback between levels

Monitoring of SDG targets is only possible if governments act efficiently and equitably, and citizens have the agency to transform their communities. Although global monitoring initiatives have an important role, they are just one part of a larger bidirectional system of information collection, analysis, and feedback that includes community, subnational, and national actors. Monitoring progress towards the SDGs requires high-quality and complete population data to inform policy, service delivery, and economic decision making. Increased attention and investment in strengthening national information systems within and across sectors, particularly in countries that have historically had weak monitoring systems, is an essential priority. This requires ongoing support for

household surveys, building national statistical capacity, and developing routine administrative systems and other subnational data systems.[349]

We propose a framework outlining how SDG indicators can be collated and monitored to enable accountability for child health and wellbeing (figure 13). Four overarching principles should guide country SDG monitoring plans. First that data collected should be aligned with national priorities. Second, data should be locally relevant. Third, data should be timely and feasible to collect. Finally, the information should contain sufficient detail to enable disaggregation by important measures of equity. National data, which contributes to global databases, comes largely from household surveys and censuses. Data openness is essential, yet roughly half of surveys and censuses are still not publicly available or are reported after long delays. This delay means national planners often have to make decisions on the basis of information that was collected several years previously or cannot undertake disaggregated analysis (eg, by rural or urban area or measures of wealth status) to inform targeted national plans.[349] Subnationally, regional or district planners and managers require locally relevant information, representative of their geographic area, that enables them to take decisions regarding the effective functioning of facilities and services across sectors.

Individuals and communities want information to assess whether services meet their needs. Data generated by citizens could be used to support improved monitoring of local sustainability activities and service delivery, as well as the effectiveness of new policies from their local government. But, what SDG indicators are suitable for community monitoring? For example, monitoring access to safe water and sanitation within schools, access to public transport, and safe spaces for recreation within communities, and coverage of essential health services are obvious candidates. Although data requirements vary for different levels of decision making and action, they are linked along a continuum with feedback loops and underscored by a commitment to upholding child rights and equity.

A dashboard for country action to improve child and adolescent wellbeing

Numerous global accountability frameworks exist to assess country progress towards the achievement of the SDGs. Countdown to 2030 and its predecessor Countdown to 2015 have played an instrumental and pioneering role in accountability for women's, children's, and adolescents' health, by generating country and equity profiles (among other successes); the Global Strategy for Women's, Children's, and Adolescents' Health (2016–2030) also translates the SDGs into concrete guidance on how to accelerate progress. The nurturing care framework is grounded in a rights-based orientation for promoting early childhood development (for which there is an SDG indicator). These components parallel those embedded in the CRC, and include good health, adequate nutrition,

Child flourishing index	Excess CO_2 emissions relative to 2030 targets (%)
1–40	<0
41–80	1–100
81–120	101–200
121–160	201–300
161–180	>300

	Sustainability rank	Flourishing rank	CO_2 per capita	Excess CO_2 emissions relative to 2030 targets (%)	World Bank classification
Qatar	180	54	49·18	1716	High income
Trinidad and Tobago	179	65	29·72	998	High income
Kuwait	178	42	25·24	832	High income
United Arab Emirates	177	49	24·66	810	High income
Bahrain	176	47	23·08	752	High income
Saudi Arabia	175	36	19·28	612	High income
Australia	174	20	16·90	524	High income
USA	173	39	16·24	500	High income
Kazakhstan	172	59	16·07	493	Upper-middle income
Luxembourg	171	11	15·93	488	High income
Canada	170	21	15·64	477	High income
Estonia	169	27	15·13	458	High income
Oman	168	61	14·06	419	High income
Turkmenistan	167	52	12·63	366	Upper-middle income
South Korea	166	2	12·08	346	High income
Russia	165	79	11·76	334	Upper-middle income
Singapore	164	12	11·34	319	High income
Iceland	163	9	10·39	284	High income
Mongolia	162	84	9·88	265	Lower-middle income
Germany	161	14	9·73	259	High income
Netherlands	160	3	9·63	256	High income
Japan	159	7	9·45	249	High income
Belgium	158	8	8·76	223	High income
Poland	157	33	8·56	216	High income
Norway	156	1	8·44	212	High income
Libya	155	74	8·37	209	Upper-middle income
Ireland	154	5	8·35	208	High income
Finland	153	16	8·32	207	High income
Iran	152	63	8·28	206	Upper-middle income
Malaysia	151	44	8·05	197	Upper-middle income
South Africa	150	127	8·05	197	Upper-middle income
Austria	149	19	8·01	196	High income
Israel	148	24	8·00	195	High income
New Zealand	147	32	7·65	183	High income
Bosnia and Herzegovina	146	38	7·60	181	Upper-middle income
Slovenia	145	25	7·02	159	High income
China	144	43	6·98	158	Upper-middle income
Bulgaria	143	45	6·93	156	Upper-middle income
Greece	142	31	6·81	151	High income
Slovakia	141	30	6·50	140	High income
The Bahamas	140	81	6·49	139	High income
Belarus	139	35	6·48	139	Upper-middle income
Seychelles	138	89	6·43	137	High income
Cyprus	137	23	6·37	135	High income
Spain	136	17	6·07	124	High income
Denmark	135	6	6·03	122	High income
Italy	134	26	5·99	121	High income

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	Sustainability rank	Flourishing rank	CO_2 per capita	Excess CO_2 emissions relative to 2030 targets (%)	World Bank classification
UK	133	10	5·81	115	High income
Turkey	132	60	5·55	105	Upper-middle income
Antigua and Barbuda	131	50	5·54	105	High income
France	130	4	5·48	102	High income
Portugal	129	22	5·31	96	High income
Equatorial Guinea	128	134	5·30	96	Upper-middle income
Hungary	127	29	5·18	91	High income
Serbia	126	48	5·13	89	Upper-middle income
Iraq	125	121	5·08	88	Upper-middle income
Venezuela	124	107	4·99	84	Upper-middle income
Ukraine	123	91	4·80	77	Lower-middle income
Thailand	122	64	4·79	77	Upper-middle income
Switzerland	121	15	4·73	75	High income
Chile	120	53	4·69	73	High income
Lithuania	119	41	4·63	71	High income
Barbados	118	51	4·63	71	High income
Argentina	117	86	4·62	70	High income
Sweden	116	13	4·19	55	High income
Montenegro	115	34	4·18	54	Upper-middle income
Croatia	114	28	4·10	51	High income
Romania	113	80	4·06	50	Upper-middle income
Azerbaijan	112	77	3·89	44	Upper-middle income
Mexico	111	88	3·80	40	Upper-middle income
Latvia	110	37	3·68	36	High income
Suriname	109	119	3·65	35	Upper-middle income
Algeria	108	85	3·64	35	Upper-middle income
Maldives	107	72	3·60	33	Upper-middle income
North Macedonia	106	40	3·48	29	Upper-middle income
Botswana	105	106	3·44	27	Upper-middle income
Mauritius	104	67	3·38	25	Upper-middle income
Malta	103	18	3·35	24	High income
Lebanon	102	73	3·21	19	Upper-middle income
Cuba	101	46	3·18	17	Upper-middle income
Uzbekistan	100	71	3·10	15	Lower-middle income
Georgia	99	76	2·80	3	Lower-middle income
Gabon	98	124	2·73	1	Upper-middle income
Jamaica	97	92	2·69	–1	Upper-middle income
Guyana	96	116	2·67	–1	Upper-middle income
Grenada	95	70	2·56	–5	Upper-middle income
Panama	94	102	2·45	–9	High income
Tunisia	93	57	2·44	–10	Lower-middle income
Saint Lucia	92	83	2·42	–11	Upper-middle income
Ecuador	91	108	2·33	–14	Upper-middle income
North Korea	90	112	2·28	–16	Low income
Brazil	89	90	2·27	–16	Upper-middle income
Egypt	88	103	2·24	–17	Lower-middle income
Jordan	87	62	2·20	–19	Upper-middle income
Albania	86	69	2·18	–20	Upper-middle income
Vietnam	85	58	2·08	–23	Lower-middle income
Saint Vincent and the Grenadines	84	95	2·02	–25	Upper-middle income
Peru	83	97	2·01	–26	Upper-middle income
Uruguay	82	66	1·98	–27	High income

(Figure 10 continues on next page)

responsive caregiving, security and safety, and opportunities for early learning. Other monitoring frameworks are embedded in strategies like the Every Newborn Action Plan, FP2020, the global Accelerated Action for the Health of Adolescents strategy, and WHO's new data portal for maternal and child health.

National governments should do formal, comprehensive child effect assessments every few years (as previously discussed); the question is how they can use these existing accountability mechanisms to construct a simple tool that can graphically display current status and gaps at different time intervals. A user-friendly tool would help highlight areas that are not on track and point to areas of success that can be learned from. The tool would be used by those involved in planning and policy making, or in advocating for children's rights. The groundwork is already well defined: the ingredients needed for children to survive, thrive, and flourish are spelled out comprehensively in the CRC. Making these ingredients available for all requires actions at multiple governmental tiers, across and within sectors, and that specific actions will depend upon the biological, social, and cognitive development of a child as they get older, and the specific context where they live.

This Commission recommends the urgent development of an adaptable country dashboard, based on country consultation and expert advice. The elements for a dashboard will make the status of children visible and catalyse investigation and action. The dashboard will be based on the rights derived from the CRC and informed by the entitlements (discussed earlier), and will monitor contextual variables that affect children's wellbeing. The CRC document emphasises environment and pollution (Article 24),[350] and the importance of environmental education (Articles 29).[350] Therefore, environmental action must be monitored to understand how well we are doing in creating a world we want for our children. As such, this dashboard could be seen as a detailed, actionable companion to the child flourishing and futures profile.

Because different development and life circumstance issues exist for different age groups throughout childhood (ie, different circumstances for infants, young children, school-age children, and adolescents), the dashboard could use a 5-year age interval, a rough, but still useful, categorisation that fits the convention of many current data collection approaches. Criteria for the selection of indicators could be those that are tier one in the SDG framework or other relevant global accountability frameworks, or which have a strong evidence base regarding what works for children and adolescents. Agreement will be needed on how to use traffic-light indicators (eg, green, yellow, red) and which cutoffs should be used to reflect good progress, moderate progress, and insufficient progress. A composite score for each country could be calculated by summing the numbers of indicators coloured green, yellow, or red. This would enable comparison of progress across

countries, particularly across countries within the same region.

Indicators should be disaggregated by key stratifiers (eg, gender, wealth quintiles, urban or rural location, ethnicity, and geographic region) where possible. A companion national equity dashboard could be considered. The indicator estimates or values would be presented along with the colour coding so that the user of the tool has a clear sense of which indicators in each domain or CRC rights area are performing well or poorly. Only datapoints for each indicator within the past 5 years will be shown on the dashboard.

We believe such a dashboard should be a high priority for governments and international bodies, and that development assistance for poorer countries should focus on strengthening data collection and analysis for priority indicators.

Citizen engagement for action and accountability

Community action will be a key determinant of countries' ability to improve children's health and wellbeing and create a sustainable world for their future. Community engagement was of course a fundamental principle of the Alma Ata declaration,[351] in 1978, and the World Development Report 2004,[352] which provided a central message that public services can be improved by strengthening accountability mechanisms between policy makers, providers, and citizens, and proposed a framework for public accountability. The SDG era, with universal rights embodied in the goals, is an opportunity to revitalise a commitment to citizen participation and engagement in monitoring with resultant action stimulated through the process.

Young people as citizen monitors

In light of the large gaps in information on children, we need transformative approaches to monitoring, including community-collected information,[353,354] grounded in lived-experiences, for credible and valid decision making on local policies and programmes. This opens the opportunity for a new role for children and youth in measuring and monitoring their own wellbeing—as active participants. More than half the world is younger than 30 years, many of whom are the hardest hit by poverty, climate change, and inequality. Young people are frequently at the forefront of change and development, through mass citizen and digital activism. Moreover, for the SDGs to meet the ambition of being truly transformative, the monitoring and accountability framework, from local to global authorities and agencies, must be people-centred, inclusive, transparent, and participatory.[353]

Citizen-generated data can provide timely information on issues that matter to the population, including those who are marginalised and hard to reach.[355,356] Furthermore, citizen-generated data can fill gaps on issues of social injustice, economic inequality, and more hidden concerns, such as disability or environmental degradation. Citizens,

	Sustainability rank	Flourishing rank	CO_2 per capita	Excess CO_2 emissions relative to 2030 targets (%)	World Bank classification
Dominican Republic	81	115	1·98	–27	Upper-middle income
Armenia	80	56	1·93	–29	Upper-middle income
Bolivia	79	118	1·89	–30	Lower-middle income
Indonesia	78	117	1·84	–32	Lower-middle income
India	77	131	1·84	–32	Lower-middle income
Costa Rica	76	75	1·77	–35	Upper-middle income
Morocco	75	105	1·76	–35	Lower-middle income
Kyrgyzstan	74	96	1·73	–36	Lower-middle income
Colombia	73	82	1·66	–39	Upper-middle income
Namibia	72	126	1·60	–41	Upper-middle income
Belize	71	94	1·50	–45	Upper-middle income
Fiji	70	93	1·48	–45	Upper-middle income
Bhutan	69	113	1·44	–47	Lower-middle income
Tonga	68	87	1·32	–51	Upper-middle income
Lesotho	67	160	1·26	–53	Lower-middle income
Moldova	66	55	1·26	–54	Lower-middle income
Guatemala	65	128	1·23	–54	Upper-middle income
Philippines	64	110	1·22	–55	Lower-middle income
Angola	63	161	1·19	–56	Lower-middle income
Samoa	62	99	1·19	–56	Upper-middle income
Honduras	61	111	1·15	–57	Lower-middle income
Sri Lanka	60	68	1·11	–59	Lower-middle income
Cape Verde	59	109	1·10	–59	Lower-middle income
El Salvador	58	104	1·10	–60	Lower-middle income
Pakistan	57	140	1·01	–63	Lower-middle income
eSwatini	56	142	0·98	–64	Lower-middle income
Papua New Guinea	55	159	0·90	–67	Lower-middle income
Nicaragua	54	101	0·87	–68	Lower-middle income
Paraguay	53	100	0·86	–68	Upper-middle income
Djibouti	52	123	0·85	–68	Lower-middle income
Yemen	51	158	0·67	–75	Low income
Benin	50	168	0·67	–75	Low income
Vanuatu	49	132	0·66	–76	Lower-middle income
Congo	48	150	0·65	–76	Lower-middle income
Mauritania	47	154	0·64	–76	Lower-middle income
Tajikistan	46	98	0·64	–76	Low income
Kiribati	45	122	0·63	–77	Lower-middle income
Zimbabwe	44	146	0·63	–77	Low income
Senegal	43	136	0·59	–78	Low income
Ghana	42	133	0·58	–79	Lower-middle income
São Tomé and Príncipe	41	125	0·57	–79	Lower-middle income
Nigeria	40	174	0·56	–79	Lower-middle income
Bangladesh	39	143	0·53	–80	Lower-middle income
Cambodia	38	114	0·50	–82	Lower-middle income
Côte d'Ivoire	37	162	0·48	–82	Lower-middle income
Myanmar	36	120	0·47	–82	Lower-middle income
Palestine*	35	78	0·47	–83	Lower-middle income
Sudan	34	149	0·45	–83	Lower-middle income
Timor-Leste	33	135	0·43	–84	Lower-middle income
Solomon Islands	32	129	0·39	–86	Lower-middle income
Togo	31	155	0·38	–86	Low income
Afghanistan	30	171	0·37	–86	Low income

(Figure 10 continues on next page)

	Sustainability rank	Flourishing rank	CO_2 per capita	Excess CO_2 emissions relative to 2030 targets (%)	World Bank classification
Mozambique	29	170	0·35	–87	Low-income
Cameroon	28	157	0·32	–88	Lower-middle income
Kenya	27	138	0·32	–88	Lower-middle income
Nepal	26	144	0·31	–89	Low-income
The Gambia	25	139	0·30	–89	Low-income
Laos	24	137	0·29	–89	Lower-middle income
Zambia	23	148	0·28	–90	Lower-middle income
Haiti	22	151	0·27	–90	Low-income
Tanzania	21	145	0·25	–91	Low-income
Comoros	20	141	0·23	–91	Low-income
Guinea	19	175	0·23	–92	Low-income
Liberia	18	169	0·23	–92	Low-income
Sierra Leone	17	172	0·18	–93	Low-income
Guinea-Bissau	16	166	0·18	–93	Low-income
Burkina Faso	15	163	0·17	–94	Low-income
Eritrea	14	147	0·16	–94	Low-income
South Sudan	13	173	0·15	–95	Low-income
Uganda	12	152	0·13	–95	Low-income
Ethiopia	11	153	0·13	–95	Low-income
Madagascar	10	165	0·12	–95	Low-income
Niger	9	177	0·12	–96	Low-income
Mali	8	176	0·09	–97	Low-income
Rwanda	7	130	0·08	–97	Low-income
Malawi	6	164	0·07	–97	Low-income
Central African Republic	5	180	0·07	–98	Low-income
Democratic Republic of the Congo	4	167	0·06	–98	Low-income
Somalia	3	178	0·05	–98	Low-income
Chad	2	179	0·05	–98	Low-income
Burundi	1	156	0·05	–98	Low-income

Figure 10: **Ranking of countries and territories on sustainable levels of carbon emissions relative to 2030 targets as a measure of a country's threat to future children, compared with child flourishing rank**
*State of Palestine/occupied Palestinian territory, including east Jerusalem.

including children and youth, can use information to raise awareness and realise rights, as outlined in Article 12 of the CRC.[350] Methods include participatory budgeting, child consultation activities, and community-based monitoring using score cards, social audits, mobile technology, and social media.[357]

Community-based monitoring ensures greater accountability in local service provision, underscored by a human-rights based approach[357] that acknowledges citizens as active agents of change who can solve problems in their own communities. A meta-case study analysis of 100 case studies of citizen engagement from 20 countries found that 75% of all cases reviewed had positive outcomes across four areas: construction of citizenship; practices of citizen participation; responsive and accountable states; and inclusive and cohesive societies. Negative outcomes included tokenistic participation, violent or coercive state responses, reinforcement of social hierarchies, and exclusion.[356] Although most evidence for community monitoring comes from small-scale studies,[357] one randomised controlled trial of citizen report cards in Uganda showed 19% less nurse absenteeism, higher immunisation uptake, a 16% higher prevalence of facility utilisation, and a 33% reduction in child mortality compared with communities who did not receive the report card intervention.[358] A similar trial done 10 years later, in a different region of Uganda, did not achieve an effect on health care utilisation prevalence or health outcomes (child mortality), but it did show a modest positive effect on treatment quality and patient satisfaction, but this effect was not mediated through citizen monitoring.[359] More evidence is needed, but positive examples exist, including an study from India which shows how change can be driven through citizen action (panel 11).

Many countries have embraced mobile technology, social media, and online platforms for citizens to hold governments to account. These initiatives are created or owned by citizens or civil society and use open-access data to track what is important to them.[362] Some examples include Infomex (Mexico), a web portal for the receipt, processing, and answering of information requests that citizens make to state government entities; FixMyStreet (UK), TXT CSC (Philippines), and Trac FM (Uganda) provide mechanisms for citizens to enquire, complain, or commend government entities on service provision; HarassMap (Egypt), Ushahidi (global), and I Paid a Bribe (12 countries globally), which collect and track information on street harassment, election violence, and petty corruption; ForestWatchers (international), a platform that collects data on deforestation; and Uwezo (Kenya, Tanzania, and Uganda) which does annual, citizen-led large scale statistically representative household assessments to measure literacy and numeracy ability in children.

Young people have driven many highly effective social movements over the past few years—including movements focusing on climate change and inequalities—characterised by self-organisation and the use of new technologies. Youth-led action can help or challenge governments to fill gaps in implementation of programmes and policy (panel 5).[362]

These youth-led social accountability mechanisms hold lessons for scaling up data collection more rapidly. Citizen-generated data, especially of a qualitative nature, on topics that affect people's lives the most, does not need to be representative to enhance our understanding of progress against SDG related targets. Furthermore, the localised nature of most citizen-generated data is exactly why they add so much value. They shed light on what is actually taking place on the ground, which can be a far more useful tool for policy making than statistical data based on national averages.[353] Although technologies hold much promise as tools for youth engagement, there could be contexts in which use of technologies might exclude certain youth from participation, such as those who are illiterate or reside in remote areas without good internet or mobile network access.

For more on **Infomex** see https://infomex.org.mx/gobiernofederal/home.action

For more on **FixMyStreet** see https://www.fixmystreet.com/

For more on **Trac FM** see https://tracfm.org/

For more on **HarassMap** see https://harassmap.org/en/

For more on **Ushahidi** see https://www.ushahidi.com/

For more on **I Paid A Bribe** see http://www.ipaidabribe.com

For more on **ForestWatchers** see http://cybermappr.unige.ch/

For more on **Uwezo** see https://www.uwezo.net/

Panel 10: Case study: a new method for measuring early child development

Accurate assessment of child development is needed to monitor children's developmental progress from birth through to school entry. Measurement tools are not necessary only for tracking progress toward global policy goals, but also to inform resource allocation and programming. However, population-based measures of child development rely predominantly on proxy indicators, such as stunting and poverty, and existing instruments to measure specific domains of individual child development are often proprietary, with commercial publishers controlling availability, cost, and standardisation. Neither the proxy nor the individual measures are adequate for programme evaluation. As of 2019, no universal measures exist that assess domains of development for children younger than 3 years old.

Three groups have recently developed new tools for measuring domains of development in children younger than 3 years old: the Infant and Young Child Development group, the Caregiver Reported Early Development Instruments group, and the Global Child Development Group. The three measures are being harmonised to develop a single measure, with a programmatic (long-form) version sensitive enough to allow quantification of the relative effects of different interventions administered within research programmes. This measure will be able to assess how study participants change and respond to interventions over time and scores will be comparable across studies; it will also permit identification of populations of children at risk of poor developmental trajectories.

The population level (short-form) version of the tool will contain a maximum of 40 questions and will be of adequate psychometric quality to inform the agreed indicator for Sustainable Development Goal 4.2.1 by generating one score for overall child development. It will be applicable to cross-sectional assessment by lay people, take a maximum of 10 minutes to administer, and be adequately sensitive to detect changes in child development over time and measure geographical, nutritional, and socioeconomic differences at population level. It is envisaged that the short-form tool will be integrated into Multiple Indicator Cluster Surveys, Demographic and Health Surveys, and other population level surveys. This version, piloted in 2019, will allow policy makers to map child development status worldwide and draw attention to vulnerable populations in humanitarian emergencies and other fragile contexts. The absence of a robust early child development instrument has hindered efforts to track progress on ensuring that children thrive and not only survive. A new method, approved by global experts, will enable policy makers, investigators, clinical personnel, and other stakeholders to assess interventions, examine data within and across countries, and use contextual data for understanding associations between predictors of development and scores on the tools. Such efforts must be seen as accompanying and driving a push toward universal early detection of developmental disabilities through appropriate screening programmes in all countries, not just in high-income countries.

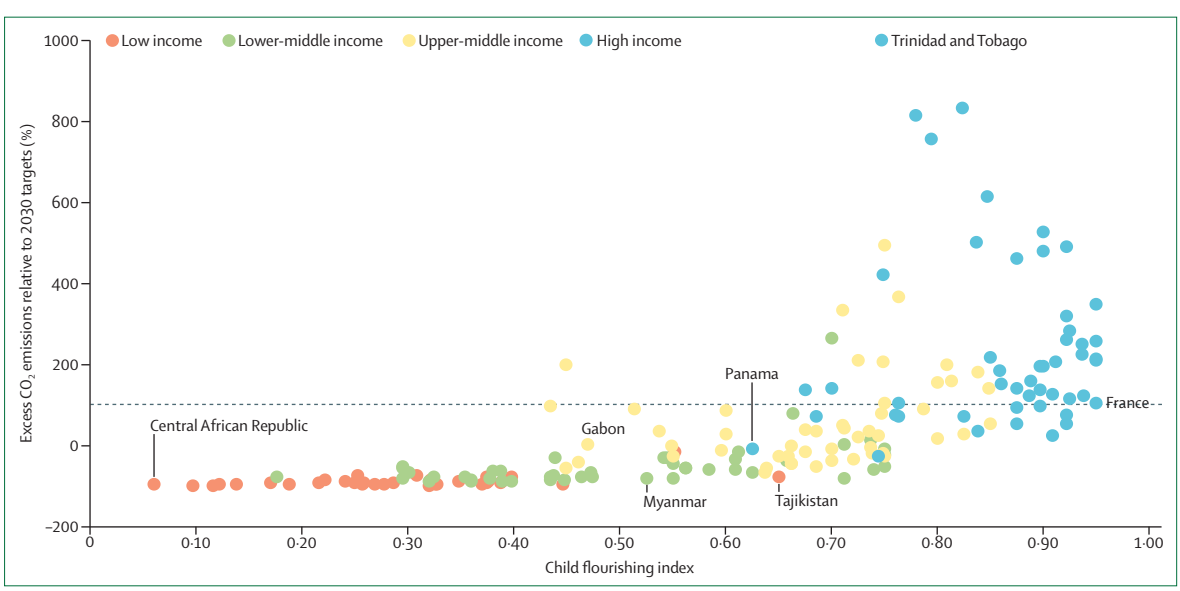

***Figure* 11: Countries' level of carbon emissions relative to 2030 targets as a measure of a country's threat to future children, compared with coefficient of child flourishing**

Data for countries and territories reporting >1000% excess CO_2 emissions are not shown in the figure.

Artificial intelligence as a support to social accountability

Artificial intelligence presents a major opportunity for engagement and accountability in the next decade. Although genuine concerns exist about artificial intelligence, the technology could be harnessed towards public good and humanitarian action in many ways. A team of scientists at Stanford University, Stanford, CA, USA, for example, have combined machine learning with high-resolution satellite

imagery to provide new data on socioeconomic indicators of poverty and wealth. Data from publicly available sources can be applied with minimal training. Georeferenced data on economic outcomes can provide important information on the distribution of poverty within countries to assist prioritisation in national planning and resource allocation.[363]

Artificial intelligence has also been applied to youth employment opportunities in South Africa, which has one of the highest youth unemployment rates in the world. Harambee, a Swahili word meaning all pull together, is a social enterprise that uses artificial intelligence to match youth with employment opportunities through geographical (including transport routes) and behavioural metrics. Youth can register without any fee and more than 1 million youth have interacted with the platform.[364]

Whether information is citizen-generated or through artificial intelligence or machine-learning processes, sustained political engagement from local politicians, decision makers, and the private sector is needed to provide dialogue on solutions. Political engagement should work across systems and sectors rather than consisting of one-off consultations addressing only single sectors (eg, health). Data provides real leverage to push for remedial action, but only if it is accompanied by a review process to discuss the implications for action. Without this engagement, social accountability mechanisms will not lead to change and the power divides between citizens and government will remain.[365]

Local government arguably has a disincentive to initiate processes that make visible their failings and inefficiences. However, from a human rights-based perspective, a responsive local government should be open to engaging with citizens and committed to implementing action to ensure progress. We need to persuade politicians that coalitions with citizens are electorally popular and can support transformational change for sustainable development.

However, without political will, or a budget to support the participation and actions of citizens, the high opportunity cost for the poorest and marginalised makes their participation less likely, which could deepen equity divides.[357] Furthermore, the skills and capacity of both government and civil society organisations to support

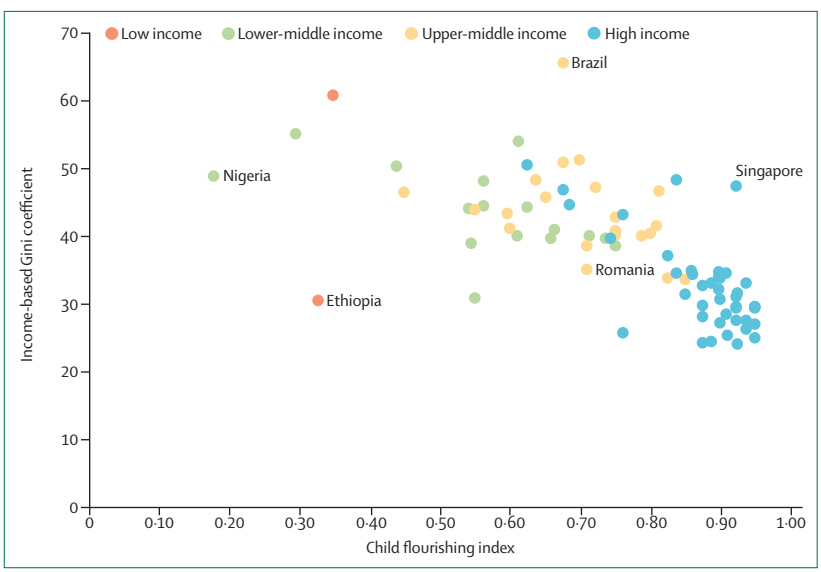

Figure 12: **Countries' level of income inequality, measured by the income-based Gini coefficient, compared with coefficient of child flourishing**
N=85 countries.

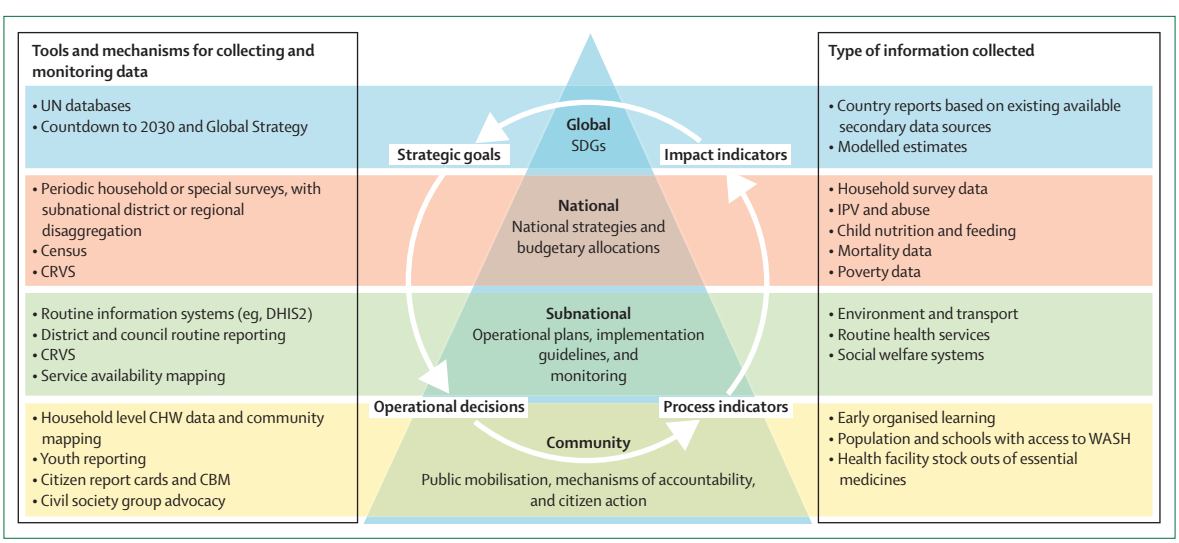

Figure 13: **Framework of levels of information collection and utilisation**
SDGs=Sustainable Development Goals. CRVS=civil registration and vital statistics. IPV=interpersonal violence. DHIS2=district health information system 2. CHW=community health workers. CBM=community-based monitoring. We propose a framework for the collection and use of data for country SDG monitoring. It is underscored by four over-arching principles: Alignment to national priorities, collection of locally relevant information, data that is timely and feasible to collect, and disaggregation of the data to ensure equity. The tools and mechanisms for data collection are outlined as is the type of information required at global, national, subnational, and community levels. A feedback loop is critical to ensure that information is shared between different levels of decision making and action.

***Panel 11:* Case study: community-based monitoring and planning of health services in Maharashtra, India**

The National Rural Health Mission, launched in India in April, 2005, has developed a comprehensive framework for community-based monitoring, which aims to improve access to high-quality health care, especially among poorer populations and women and children in rural areas. Community-based monitoring has been piloted in nine states in India. In the state of Maharastra, 500 villages are covered with plans to expand coverage to 750 villages.

Process

Village meetings, distribution of educational materials, expansion and strengthening of village health committees (VHCs), and training of VHC members are used to enhance community awareness and involvement in the process of health accountability. Multistakeholder community monitoring committees are formed at primary health-care centres at block and district levels. These committees include community members, civil society representatives, elected political representatives, and public health staff. Committee members periodically collect information about health service delivery using simple, pictorial semi-quantitative tools, and rate these through publicly displayed report cards, with each service being rated as good, partly satisfactory, or bad. This data is collected both in villages (concerning outreach services) and in health-care facilities.

Public hearings, or Jan Sunwai, with mass participation are organised at primary health-care centres, to present report cards and cases of health-care denial. Health-care officials are called upon publicly to respond regarding remedial actions. Periodic state-wide events enable dialogue between civil society monitoring committee members and the state health department, seeking resolution of unresolved and systemic issues, and help reinforce government support for the community-based monitoring process.[360]

Outcomes

According to state officials, communities have increased public awareness of their rights and empowerment to demand these rights. For example, public involvement in the Jan Sunwai (public hearings) has helped people realise the importance of antenatal care check-ups and improved access and demand for these services. There has also been enhanced accountability from government officials who are confronted on an egalitarian platform through dialogue, and who have addressed long-neglected concerns, such as timely maintenance of clinics, or taken action against corrupt providers.[361]

Community-driven data collection and periodic review has the potential to effectively monitor the provision of entitlements, medicine stocks, human resource deployment, quality of care and attitudinal issues. However, more research is needed on whether so-called bottom-up initiatives for community-driven collection and use of data can effectively contribute to monitoring and planning health policies and programmes, including those relevant to children's health and wellbeing, and their potential for wider scale-up.

social accountability are essential. To effectively support community monitoring and social accountability, civil society organisations need not only funding but also literacy, technical skills, and knowledge of their rights.[357]

A collaborative approach between governments, civil society organisations, and other stakeholders can build local social accountability mechanisms, in which citizens and civil society play a decisive and formal role,[366] and should be embedded as part of the fabric of people's day-to-day lives.

Summary

Here, we reviewed the data and accountability landscape around child health and wellbeing, with a focus on how to monitor, review, and act on data in the SDG era. We reviewed the large gaps in current data processes and highlighted the urgency of investment to strengthen country information systems and capacities to collect, analyse and act on information capitalising on suitable technology to reduce the burden on the public work force. We then proposed some solutions, including a colour-coded child flourishing and futures profile (figure 10) largely on the basis of available country data from the SDGs and carbon emissions, a compact and actionable dashboard to help countries guide their action, and citizen and youth-led monitoring to fill in the gaps. We now turn to our conclusions and key recommendations (panel 1) around how to build a new global movement for children's health and wellbeing at the centre of the SDGs.

Conclusion

We live in an era like no other. Our children face a future of great opportunity, but they stand on the precipice of a climate crisis. Working together, the world's countries have agreed to the SDG framework to usher future generations into a cleaner, healthier world, but the SDG agenda has yet to gain traction. Our challenge is great and we seem to be paralysed.

This Commission proposes a new global movement to place children at the centre of the SDGs. The CRC is the world's most ratified human rights treaty, showing the power of children to unite us for the common good. Working to improve children's health and wellbeing can motivate all of us to save our planet for them and for ourselves.

In this Commission, we have purposefully taken a high-level view of the problem of child health and wellbeing. First, we have argued for a life course and intergenerational approach to show that the benefits of intervening to improve child health and wellbeing are multiplied many times over the life of the child and their descendants. The economic and ethical case is unbeatable. We also show

how all sectors are responsible for children and lay out an agenda to unite them to work together.

Second, we operationalised this agenda by summarising a set of entitlements for children that have already been agreed upon by the world's countries. We have also described how families, communities, and governments can mobilise to deliver them. The effort required is enormous, but if we cannot deliver for our children, what is the measure of our civilisation?

Third, such an enormous collective project requires governance. We have laid out the changes to governance required at national, local, and global levels. Given that children's health and wellbeing is the concern of all sectors, we paid special attention to multisectoral collaboration, as well as vertical coordination between the various governance levels, to make sure our efforts are synergised for maximum effect.

Fourth, we extended our discussion of governance to discuss the regulation of commercial marketing. The commercial threats to children's health are dangerously underappreciated, and we propose strong, specific actions for global and national actors to protect children from rapacious, unregulated commercial practices.

Finally, what gets measured, gets done. We have taken a hard look at data and accountability under the SDGs, and find that current efforts are severely wanting. Only the participation of citizens, communities, and children themselves can overcome the enormous data gaps for the SDGs, and because assessment of countries' performance must include a measure of sustainability to protect our children's future and their present, we have proposed a children's flourishing and futures profile to do just that.

Although awed by the scale of our task, this Commission is also optimistic about our chances to change our world for the better, for and with children. It will require bold politicians, courageous community leaders, and international agencies that are willing to radically change the way they work. No excuses, and no time to lose.

Contributors

Initial sections of the Commission were contributed by writing teams led by ASG, JSh, TD, TP-J, and SA. LG designed the child flourishing index and child futures profile. Full drafts were prepared by a core writing team led by AC and SLD, based on contributions from writing team members. All commissioners participated in creating Commission content, shaping the overall Commission structure, writing and editing drafts, and formulating conclusions and recommendations. The Commission was prepared under the general direction of HC, AMC-S, and AC. Further data gathering and analyses were done by a supporting team listed in the Acknowledgments. The authors alone are responsible for the views expressed in this Commission and they do not necessarily represent the views, decisions or policies of the institutions with which they are affiliated, or those of WHO or UNICEF. The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO and UNICEF concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Declaration of interests

This Commission was funded by the Bill & Melinda Gates Foundation (Seattle, WA, USA) and all authors received support from the foundation via WHO to attend meetings. AB, KR, KS, NR, and JSi are employees of WHO; and SP, DBH, and JR are employees of UNICEF. AC received grants from WHO; and received personal fees from the Bill & Melinda Gates Foundation. SLD received personal fees from the Bill & Melinda Gates Foundation and WHO for the submitted Commission and for work outside of the published work. LG received personal fees from the Bill & Melinda Gates Foundation (via WHO). YRS received personal fees from the Bill & Melinda Gates Foundation (via WHO). SSR received personal fees from the Bill & Melinda Gates Foundation (via WHO). AB received funding from the Bill & Melinda Gates Foundation. JB received a grant from the Bill & Melinda Gates Foundation. JSi received a grant from the Bill & Melinda Gates Foundation AG reports grants from the United States Agency for International Development Center for Accelerating Innovation and Impact, UNICEF, Rockefeller Foundation, and World Bank outside of the submitted work. MT has received grants from the Conrad Hilton Foundation outside of the submitted work. ASG is supported by the South African Research Chair's Initiative of the Department of Science and Technology and National Research Foundation of South Africa (Grant No 82769) and the South African Medical Research Council. All other authors report no competing interests.

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Editorial note: the *Lancet* Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

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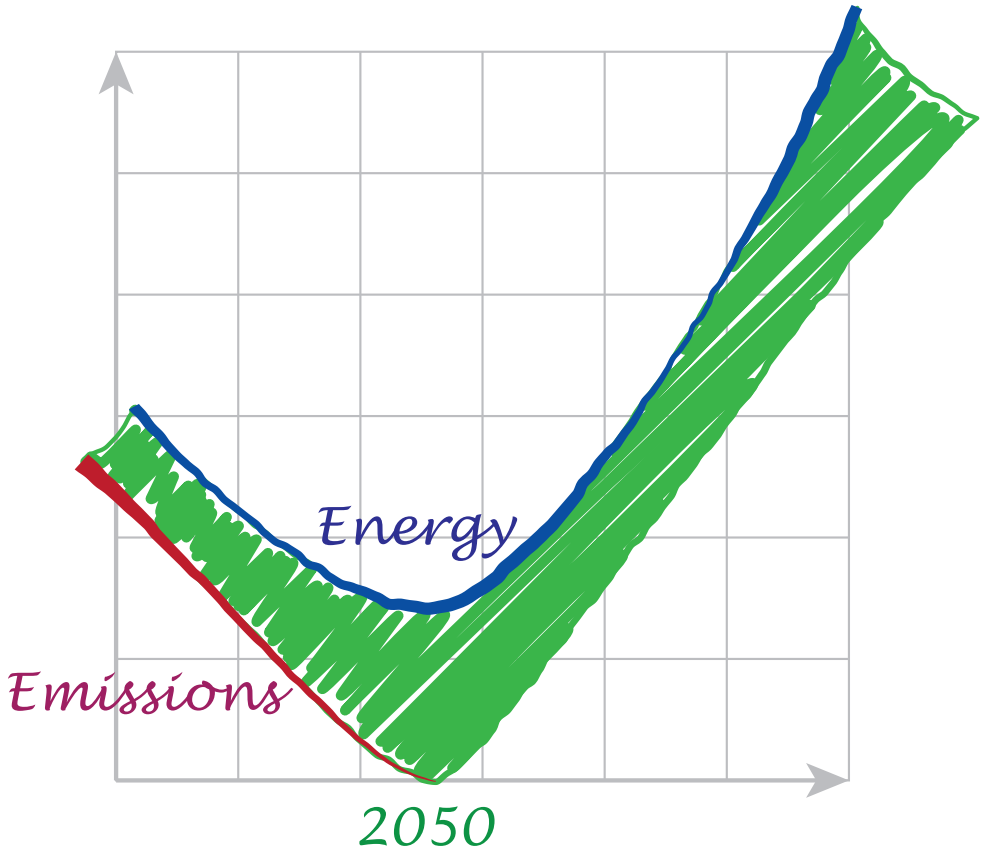
Absolute Zero



Delivering the UK's climate change commitment with incremental changes to today's technologies

UK FIRES

Absolute Zero

UK demand for energy-intensive materials is growing, driving increased emissions in the UK and abroad. UK FIRES is a research programme sponsored by the UK Government, aiming to support a 20% cut in the UK's true emissions by 2050 by placing Resource Efficiency at the heart of the UK's Future Industrial Strategy.

Industry is the most challenging sector for climate mitigation – it's energy efficient and there are no substitutes available at scale for the energy-intensive bulk materials - steel, cement, plastic, paper and aluminium. UK FIRES is therefore working towards an industrial renaissance in the UK, with high-value climate-safe UK businesses delivering goods and services compatible with the UK's legal commitment to zero emissions and with much less new material production.

UK FIRES

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Executive Summary

We can't wait for breakthrough technologies to deliver net-zero emissions by 2050. Instead, we can plan to respond to climate change using today's technologies with incremental change. This will reveal many opportunities for growth but requires a public discussion about future lifestyles.

We have to cut our greenhouse gas emissions to zero by 2050: that's what climate scientists tell us, it's what social protesters are asking for and it's now the law in the UK. But we aren't on track. For twenty years we've been trying to solve the problem with new or **breakthrough** technologies that supply energy and allow industry to keep growing, so we don't have to change our lifestyles. But although some exciting new technology options are being developed, it will take a long time to deploy them, and they won't be operating at scale within thirty years.

Meanwhile, our cars are getting heavier, we're flying more each year and we heat our homes to higher temperatures. We all know that this makes no sense, but it's difficult to start discussing how we really want to address climate change while we keep hoping that new technologies will take the problem away.

In response, this report starts from **today's technologies**: if we really want to reach zero emissions in thirty years time, what does that involve? Most of what we most enjoy - spending time together as families or communities, leisure, sport, creativity - can continue and grow unhindered. We need to switch to using electricity as our only form of energy and if we continue today's impressive rates of growth in non-emitting generation, we'll only have to cut our use of energy to 60% of today's levels. We can achieve this with **incremental** changes to the way we use energy: we can drive smaller cars and take the train when possible, use efficient electric heat-pumps to keep warm and buy buildings, vehicles and equipment that are better designed and last much longer.

The two big challenges we face with an all electric future are **flying** and **shipping**. Although there are lots of new ideas about electric planes, they won't be operating at commercial scales within 30 years, so zero emissions means that for some period, we'll all stop using aeroplanes. Shipping is more challenging: although there are a few military ships run by nuclear reactors, we currently don't have any large electric merchant ships, but we depend strongly on shipping for imported food and goods.

In addition, obeying the law of our Climate Change Act requires that we stop doing anything that causes emissions regardless of its energy source. This requires that we stop eating **beef and lamb** - ruminants who release methane as they digest grass - and already many people have started to switch to more vegetarian diets. However the most difficult problem is **cement**: making cement releases emissions regardless of how it's powered, there are currently no alternative options available at scale, and we don't know how to install new renewables or make new energy efficient buildings without it.

We need to discuss these challenges as a society. Making progress on climate change requires that the three key groups of players - government, businesses and individuals - work together, rather than waiting for the other two to act first. But until we face up to the fact that breakthrough technologies won't arrive fast enough, we can't even begin having the right discussion.

Committing to zero emissions creates tremendous **opportunities**: there will be huge growth in the use and conversion of electricity for travel, warmth and in industry; growth in new zero emissions diets; growth in materials production, manufacturing and construction compatible with zero emissions; growth in leisure and domestic travel; growth in businesses that help us to use energy efficiently and to conserve the value in materials.

Bringing about this change, and exploring the opportunities it creates requires three things to happen together: as individuals we need to be part of the process, exploring the changes in lifestyle we prefer in order to make zero emission a reality. **Protest is no longer enough** - we must together discuss the way we want the solution to develop; the government needs to treat this as **a delivery challenge** - just like we did with the London Olympics, on-time and on-budget; the emitting businesses that must close cannot be allowed to delay action, but meanwhile the authors of this report are funded by the government to work across industry to support the **transition to growth compatible with zero emissions**.

Breakthrough technologies will be important in the future but we cannot depend on them to reach our zero emissions target in 2050. Instead this report sets an agenda for a long-overdue public conversation across the whole of UK society about how we really want to achieve Absolute Zero within thirty years.

Key messages for industrial sectors

Key Message: Absolute Zero creates a driver for tremendous growth in industries related to electrification, from material supply, through generation and storage to end-use. The fossil fuel, cement, shipping and aviation industries face rapid contraction, while construction and many manufacturing sectors can continue at today's scales, with appropriate transformations.

Leisure, sports, creative arts and voluntary work: These sectors can expand greatly and should have a central position in national definitions of welfare targets.

Electricity sector and infrastructure: Absolute Zero requires a 3x expansion in non-emitting electricity generation, storage, distribution and load-balancing.

Construction sector: All new builds should be to zero-energy standards of use. The impacts of construction are primarily about the use of materials: primarily steel and cement. By 2050, we will have only very limited cementitious material and will use only recycled steel, but there are myriad opportunities for radical reductions in the amount of material used in each construction.

Steel sector: All exsiting forms of blast furnace production, which are already under great pressure due to global over-capacity, are not compatible with zero-emissions. However, recycling powered by renewables, has tremedous opportunities for growth exploiting the fact that steel scrap supply will treble in the next 30 years. There are short term innovation opportunities related to delivering the highest quality of steel from recycling, and longer-term opportunities for technologies for zero-carbon steel making from ore that could be deployed after 2050.

Cement sector: All existing forms of cement production are incompatible with zero emissions. However, there are some opportunities for expanded use of clay and urgent need to develop alternative processes and materials. Using microwaves processes to recycle used cement appears promising.

Mining and material supply: Zero emissions will drive a rapid transition in material requirements. Significant reduction in demand for some ores and minerals, particularly those associated with steel and cement, are likely along with a rapid expansion of demand for materials associated with electrification. It seems likely that there will be opportunities for conslidation in the currently diffuse businesses of secondary material collection, processing, inventory and supply.

Rail: The great efficiency of electric rail travel suggests a significant expansion in this area, domestically and internationally, is likely and would see high demand. The most efficient electric trains are aerodynamically efficient, like those designed for the highest speed operation today, but travelling at lower speeds.

Road vehicles: The transition to electric cars is already well under-way, and with increasing demand, costs will presumably fall. We already have targets for phasing out non electric vehicles, but by 2050 will have only 60% of the electricity required to power a fleet equivalent to that in use today. Therefore we will either use 40% fewer cars or they will be 60% the size. Development of auto-grade steels from recycling is a priority, and the need to control recycled metal quality may require changed models of ownership. The rapid expansion of lithium battery production may hit short-term supply constraints and create environmental concerns at end-of-life unless efficient recycling can be developed.

International freight: We currently have no non-emitting freight ships, so there is an urgent need for exploration of means to electrify ship power, and options to transfer to electric rail. This would require an enormous expansion in international rail capacity.

Aviation: There are no options for zero-emissions flight in the time available for action, so the industry faces a rapid contraction. Developments in electric flight may be relevant beyond 2050.

Fossil fuel industries: All coal, gas, and oil-fuel supply from extraction through the supply chain to retail must close within 30 years, although carbon capture and storage may allow some activity later.

Travel and tourism: Without flying, there will be growth in domestic and train-reach tourism and leisure.

Food and agriculture: Beef and lamb phased out by 2050 and replaced by greatly expanded demand for vegetarian food. Electricity supply for food processing and storage will be cut by 50%.

Building maintenance and retrofit: Rapid growth in demand for conversion to electric heat-pump based heating matched to improvements in insulation and air-tightness for building envelopes.

Key messages for individuals

Key Message: The big actions are: travel less distance, travel by train or in small (or full) electric cars and stop flying; use the heating less and electrify the boiler when next upgrading; lobby for construction with half the material for twice as long; stop eating beef and lamb. Each action we take to reduce emissions, at home or at work, creates a positive ripple effect.

As individuals we can all work towards Absolute Zero through our purchasing and our influence. Each positive action we take has a double effect: it reduces emissions directly and it encourages governments and businesses to be bolder in response. Where we cause emissions directly we can have a big effect by purchasing differently. Where they are released by organisations rather than individuals, we can lobby for change.

The actions stated as absolutes below are those which will be illegal in 2050 due to the Climate Change Act.

Living well

The activities we most enjoy, according to the UK's comprehensive time-use survey, are sports, social-life, eating, hobbies, games, computing, reading, tv, music, radio, volunteering (and sleeping!) We can all do more of these without any impact on emissions.

Travelling

The impact of our travelling depends on how far we travel and how we do it. The most efficient way to travel is with a large number of people travelling in a vehicle with a small front, and we can all reduce our total annual mileage.

1. Stop using aeroplanes
2. Take the train not the car when possible.
3. Use all the seats in the car or get a smaller one
4. Choose an electric car next time, if possible, which will become easier as prices fall and charging infrastructure expands.
5. Lobby for more trains, no new roads, airport closure and more renewable electricity.

Heating and appliances:

Our energy bills are mainly driven by our heating and hot water.

1. Use the boiler for less time, if possible, staying warm by only heating rooms if people are sitting in them, sealing up air gaps and adding insulation.
2. Wear warmer clothes in winter.
3. Next time you replace the boiler, choose an electric air or ground-source heat pump if possible
4. Buy smaller more efficient appliances that last longer
5. Lobby for zero-carbon building standards, means-tested support for housing retrofit and more renewable electricity

Purchasing:

Most industrial emissions relate to producing materials, which are made efficiently but used wastefully so we need to reduce the weight of material made. The highest volumes of material are used not by households, but to make commercial and public buildings and infrastructure, industrial equipment and vehicles.

1. Lobby businesses and the government to make buildings and infrastructure with half the material guaranteed to last for twice as long.
2. When extending or modifying your home, try to choose recycled or re-used materials and avoid cement.
3. Aim to reduce the total weight of material you purchase each year.
4. Lobby for border controls on emissions in materials (like we have with food standards) to allow businesses fit for Absolute Zero to grow and prosper in the UK

Eating:

Small changes in diet can have a big effect.

1. Reduce consumption of beef and lamb as these have far higher emissions than any other common food.
2. Choose more locally sourced food if possible, to reduce food miles, particularly aiming to cut out air-freighted foods.
3. Aim to use less frozen and processed meals as these dominate the energy use of food manufacturers.
4. Lobby supermarkets to support farmers in using less fertiliser - it has a high impact, but much of it is wasted as it's spread too far away from the plants.

Why this report matters

Key Message: We are legally committed to reducing the UK's emissions to zero by 2050, and there isn't time to do this by deploying technologies that don't yet operate at scale. We need a public discussion about the changes required and how to convert them into a great Industrial Strategy.

Timelines:

In her last significant act as Prime Minister, Theresa May changed the UK's Climate Change Act to commit us to eliminating all greenhouse gas emissions in the UK by 2050. This decision is based on good climate-science, was a response to a great wave of social protest and has been replicated in 60 other countries already.

However, 30 years is a short time for such a big change. Politicians in the UK and internationally talk about climate change as if it can be solved by new energy technologies alone, and UK government reports are over-confident about how much progress has been achieved; in reality most UK cuts in emissions have been as a result of Mrs Thatcher's decision to switch from coal to gas fired electricity and to allow UK heavy industry to close. The UK has been successul in reducing methane emissions - by separating our organic waste and using it in anaerobic digesters to make gas for energy, but new energy technologies are developing slowly.

There are no invisible solutions to climate change so we urgently need to engage everyone in the process of delivering the changes that will lead to zero emissions.

Confusion about technologies

In this report we're using three different descriptions of the technologies which cause emissions:

- **Today's technologies** are the mass-market products of today - such as typical petrol or diesel cars.
- **Incremental technologies** could be delivered today if customers asked for them - for example smaller cars.
- **Breakthrough technologies** such as cars powered by hydrogen fuel cells, may already exist, but haven't yet captured even 5% of the world market.

Incremental technologies can be deployed rapidly, but breakthrough technologies can't. We're concerned that most plans for dealing with climate change depend on breakthrough technologies - so won't deliver in time.

Why we've written this report now

The authors of this report are funded by the UK government to support businesses and governments (national and regional) to develop a future Industrial Strategy that's compatible with Zero Emissions. To do that, we have to anticipate how we'll make future goods and buildings, and also think about what performance we want from them.

What we mean by "Absolute Zero"

The UK's Climate Change Act contains two "escape" words: it discusses "net" emissions and targets on those that occur on our "territory." However, in reality, apart from planting more trees, we don't have any short-term options to remove emissions from the atmosphere, and even a massive expansion in forestry would have only a small effect compared to today's emissions. Furthermore, shutting factories in the UK doesn't make any change to global emissions, and may make them worse if we import goods from countries with less efficient processes.

Public concern about the Climate is too well informed to be side-lined by political trickery on definitions. In writing this report, we have therefore assumed that:

- the target of zero emissions is absolute - there are no negative emissions options or meaningful "carbon offsets." Absolute Zero means zero emissions;
- the UK is responsible for all emissions caused by its purchasing, including imported goods, international flights and shipping.

Invitation to participate

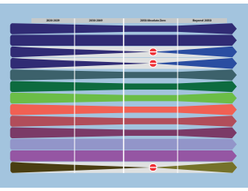
This report presents our best estimate of Absolute Zero, based on publicly reported data and peer-reviewed evidence. Undoubtedly there are more opportunities that we don't know of, and if this report proves useful, there will be other aspects of the journey to Absolute Zero that we can help to inform. We welcome contributions and comment and will provide an edited summary of any discussion on www.ukfires.org. If there is demand, we will update and re-issue the report in response.

Please contact us via info@ukfires.org and if you found this report useful, please share it through your networks.

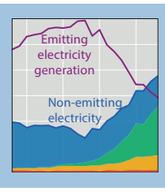
Guide to the report

Opening material

What actions can we take - as individuals and in the key sectors to reduce emissions now and to develop future choices to deliver Absolute Zero?



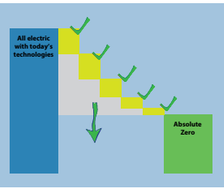
1. Absolute Zero with today's technologies



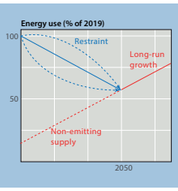
The UK Climate Change Act commits us to zero emissions in 30 years time - based on good climate science. The lowest risk way to get there is to change the way we use today's technologies.

2. Options for incremental and breakthrough innovations

The goods we buy will of course change over the next 30 years, but it takes decades for breakthrough technologies to reach full scale, so we focus on likely incremental innovations.



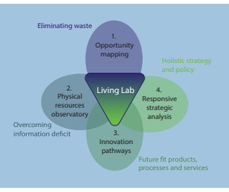
3. The process of change towards Absolute Zero



Reaching Absolute Zero requires a collaboration between individuals, government and businesses. None of them can act unilaterally, so reaching the target will be a process.

4. Opportunities created by Absolute Zero

One of the benefits of considering Absolute Zero is that it allows us to recognise how many opportunities are created by pursuing the strict emissions target.



Notes to the figures

Notes to the figures

Figure 1.2: Data from the International Energy Agency (IEA, 2018) with data on CCS installations at power-stations from the Oil and Gas funded pro-CCS lobby, Global CCS Institute.

Figure 1.3: This analysis by Vaclav Smil (2014) looks at global deployments of the three major fossil fuels, relative to total world energy demand at the time. Some faster transitions have occurred in individual countires, as shown in the box story on page 3.

We've tried to make this report as easy to read as possible, but all our analysis is firmly rooted in data. These notes show how we've sourced and used the evidence

References

These references point to the sources we used for data or other evidence.

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HM Government, 2018. Our waste, our resources ...

	2020-2029	2030-2049	2050 Absolute Zero	Beyond 2050
Road vehicles	Development of petrol/diesel engines ends; Any new vehicle introduced from now on must be compatible with Absolute Zero	All new vehicles electric, average size of cars reduces to ~1000kg.	Road use at 60% of 2020 levels - through reducing distance travelled or reducing vehicle weight	New options for energy storage linked to expanding non-emitting electricity may allow demand growth
Rail	Growth in domenstic and international rail as substitute for flights and low-occupancy car travel	Further growth with expanded network and all electric trains; rail becomes dominant mode for freight as shipping declines	Electric trains the preferred mode of travel for people and freight over all significant distances,	Train speeds increase with increasing availability of zero emissions electricity
Flying	All airports except Heathrow, Glasgow and Belfast close with transfers by rail	All remaining airports close		Electric planes may fly with synthetic fuel once there are excess non-emitting electricity supplies
Shipping	There are currently no freight ships operating without emissions, so shipping must contract	All shipping declines to zero.		Some naval ships operate with onboard nuclear power and new storage options may allow electric power
Heating	Electric heat pumps replace gas boilers. and building retrofits (air tightness, insulation and external shading) expand rapidly	Programme to provide all interior heat with heat pumps and energy retroifts for all buildings	Heating powered on for 60% of today's use.	Option to increase use of heating and cooling as supply of non-emitting electricity expands
Appliances	Gas cookers phased out rapidly in favour of electric hobs and ovens. Fridges, freezers and washing machines become smaller.	Electrification of all appliances and reduction in size to cut power requirement.	All appliances meet stringent efficiency standards, to use 60% of today's energy.	Use , number and size of appliances may increase with increasing zero-emnissions electricity supply
Food	National consumption of beef and lamb drops by 50%, along with reduction in frozen ready meals and air-freighted food imports	Beef and lamb phased out, along with all imports not transported by train; fertiliser use greatly reduced	Total energy required to cook or transport food reduced to 60%.	Energy available for fertilising, transporting and cooking increases with zero-emissions electricity
Mining material sourcing	Reduced demand for iron ore and limestone as blast furnace iron and cement reduces. Increased demand for materials for electrification	Iron ore and Limestone phased out while metal scrap supply chain expands greatly and develops with very high precision sorting	Demand for scrap steel and ores for electrification much higher, no iron ore or limestone.	Demand for iron ore and limestone may develop again if CCS applied to cement and iron production
Materials production	Steel recycling grows while cement and blast furnace iron reduce; some plastics with process emissions reduce.	Cement and new steel phased out along with emitting plastics . Steel recycling grows. Aluminium, paper reduced with energy supply.	All materials production electric with total 60% power availability compared to 2020	Material production may expand with electricity and CCS, CCU, hydrogen may enable new cement and steel.
Construction	Reduced cement supply compensated by improved material efficiency, new steel replaced by recycled steel	All conventional mortar and concrete phased out, all steel recycled. Focus on retrofit and adaption of existing buildings.	Any cement must be produced in closed-loop, new builds highly optimised for material saving.	Growth in cement replacements to allow more architectural freedom; new steel may become available.
Manufacturing	Material efficiency becomes promiment as material supply contracts	Most goods made with 50% as much material, many now used for twice as long	Manufacturing inputs reduced by 50% compensated by new designs and manufacturing practices. No necessary reduction output.	Restoration of reduced material supplies allows expansion in output, although some goods will in future be smaller and used for longer than previously.
Electricity	Wind and solar supplies grow as rapidly as possible, with associated storage and distribution. Rapid expansion in electrifiiciation of end-uses.	Four-fold increase in renewable generation from 2020, all non-electrical motors and heaters phased out.	All energy supply is now non-emitting electricity.	Demand for non-emitting electricity drives ongoing expansion in supply.
Fossil fuels	Rapid reduction in supply and use of all fossil fuels, except for oil for plastic production	Fossil fuels completed phased out		Development of Carbon Capture and Storage (CCS) may allow resumption of use of gas and coal for electricity

1. Zero emissions in 2050 with today's technologies

Key Message: Apart from flying and shipping, all of our current uses of energy could be electrified. With tremendous commitment the UK could generate enough non-emitting electricity to deliver about 60% of our current final energy-demand, but we could make better use of that through incremental changes in the technologies that convert energy into transport, heating and products.

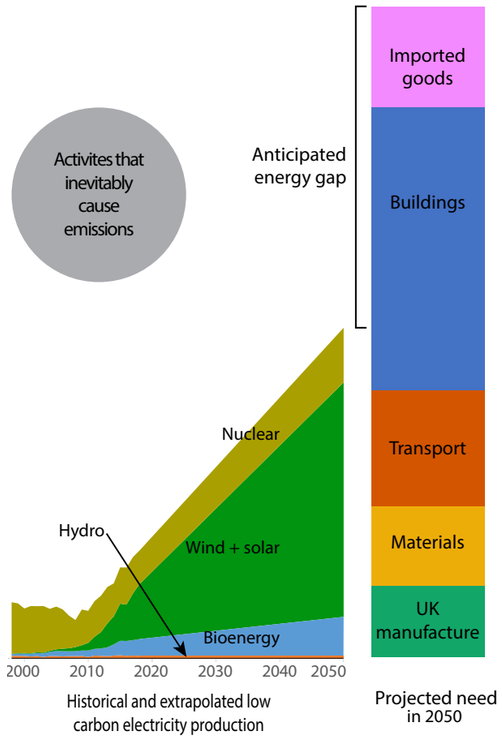
About three quarters of the greenhouse gas emissions caused by humans are emitted when we burn the fossil fuels - coal, gas and oil - and the rest arise from our agriculture (particularly cows and sheep), our conversion of land from forestry to pasture, the way we allow organic waste to decompose, and our industrial processes. Using today's technologies, all of these sources unrelated to energy have no alternative, so reducing our emissions to zero means phasing out these activities.

Our emissions related to energy come from our use of oil (as diesel, petrol or kerosene) for transport, our use of gas for heating our homes and industrial processes, and our use of coal and gas to generate electricity. Some of our electricity is also generated without burning fossil fuels - for instance by nuclear power stations, wind turbines or solar cells - and in a zero emissions future these will be our only source of energy. Most of our current uses of energy could be electrified - as is becoming familiar with electric cars - but there are currently no options for electric flying or shipping. With today's technologies, these modes of transport must therefore be phased out also.

Over the past 10 years in the UK, we have made a significant change to the way we generate electricity and about half of our generation is now from non-emitting sources. If we continue developing the generation system at the same rate, then by 2050 we will have around 50% more electric power than we have today. Data on the efficiencies of today's motors and heaters allows us to estimate that this will be enough to power about 60% of today's energy-using activities (apart from flying and shipping). However, because energy has been so cheap and abundant in the past 100 years, in many cases we could make small changes to existing technologies to make much better use of less energy.

Fig. 1.1 summarises this overview of Absolute Zero with today's technologies: the left side of the figure shows the recent history of the UK's non-emitting electricity generaton extrapolated forwards to 2050. The right side shows the amount of electricity we'd need if we electrified everything we do today, apart from those activities that inevitably cause emissions, which we'll have to phase out.

Figure 1.1: Gap between today and Absolute Zero



1.1 Energy Supply Today

The science is clear: we must stop adding to the stock of greenhouse gases in the atmosphere to control global warming. In response, the best estimates of science today predict that annual global emissions from human activities must be reduced rapidly and should be eliminated by 2050 – in thirty years' time. This target, which requires extraordinarily rapid change, is now law in the UK, and several other countries. However, despite the science and the laws, global emissions are still rising.

The critical choice in planning to cut emissions is about the balance between technology innovation and social choice. Is it possible to develop a new technology that will cut emissions while allowing people in developed economies to continue to live as we do today and to allow developing economies to develop the same behaviours? Or should we first modify our behaviour to reach the emissions target, with different aspirations for development, and then take the benefits of technology innovation when they become available later? To date, as illustrated in Fig. 1.2, every national and international every national and international government plan for responding to climate change has chosen to prioritise technology innovation, yet global emissions are still rising.

For twenty years, two technologies have dominated policy discussions about mitigating climate change: renewable energy generation and carbon capture and storage (CCS). The two renewable technologies now being deployed widely are wind-turbines and solar-cells. These critical forms of electricity generation are essential, and should be deployed as fast as possible, but Fig. 1.3 shows that, they combined with nuclear power and hydro-electricity, still contribute only a small fraction of total global energy demand. Meanwhile, although CCS has been used to increase rates of oil extraction, its total contribution to reducing global emissions is too small to be seen. The technological elements of CCS have all been proven at some scale, but until a first fleet of full-scale power-plants are operating, the risks and costs of further expansion will remain high and uncertain. To illustrate the current importance of CCS in global power generation, the total

Figure 1.2: Acting now or waiting for new technologies

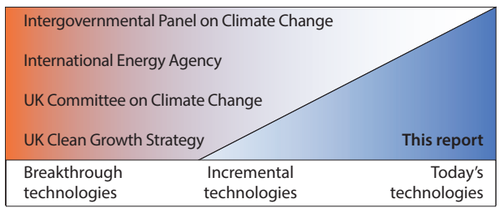
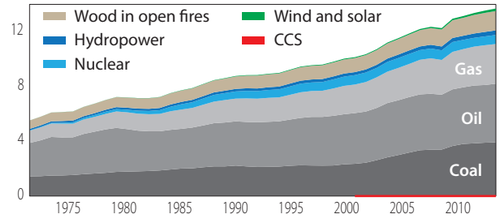


Figure 1.3: World primary energy supply ('000 Mtoe)

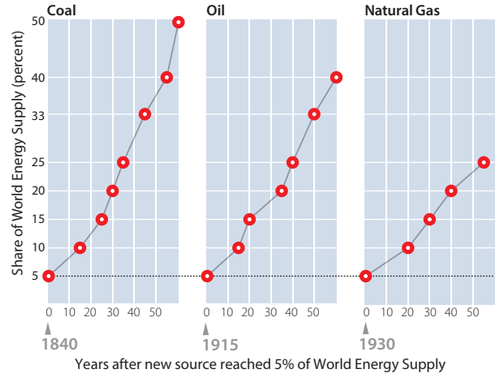


output of all CCS enabled power-generation is shown on Fig. 1.3 - still very definitely on top of the y-axis.

All previous transitions in the energy system, for example in Fig. 1.4, have occurred relatively slowly. Early installations experience problems due to human error, and the installation of large generation requires lengthy public consultation on land-rights, environmental protection, safety and financing. Despite this, CCS looks very attractive to policy makers. Twenty years ago, the International Energy Agency stated that "within 10 years we need 10 demonstrators of CCS power stations" but none are operating at full-scale today. Yet in 2019 the UK's Climate Change Committee published its plans to deliver zero emissions, requiring deployment of CCS in six of thirteen sectors within thirty years. However, the UK has no current plans for even a first installation and although CCS may be important in future, it is not yet operating at meaningful scale, but meanwhile global emissions are still rising.

The hope of an invisible, technology-led, solution to climate change is obviously attractive to politicians and incumbent businesses. However, a result of their focus on this approach has been to inhibit examination of our patterns of energy demand. Fig. 1.6a shows that the UK's demand for energy is only falling in industry. This is because in the absence of a meaningful industrial strategy, we have closed our own industry in favour of increased imports. As a result, this apparent reduction in energy

Figure 1.4: Major transitions in global energy supply



Technology Transitions in the Energy System

New computers, clothes and magazines can be put on sale soon after the are invented. However new energy technologies have typically required much longer time to reach full scale: even if the technology is well-established, building a power station requires public consultation about finance, safety, land-rights, connectivity and other environmental impacts all of which take time. For new technologies, it takes much longer, as investors, operators and regulators all need to build confidence in the safety and perfomance of the system. Figure 1.5 summarises the rates of introduction of various new energy technologies in the countries where they grew most rapidly. The green arrow corresponds to the start points of the linear periods of growth shown in Fig. 1.4.

Figure 1.5: Years to deploy energy technologies

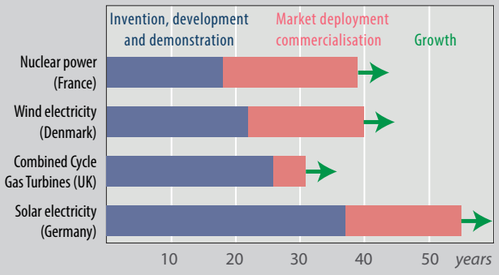
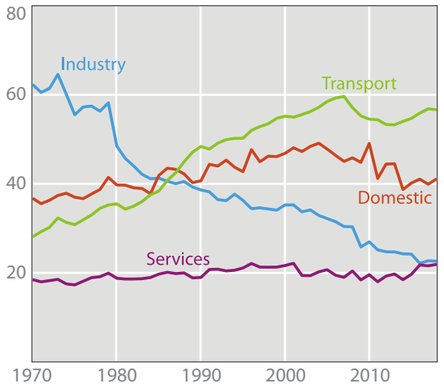
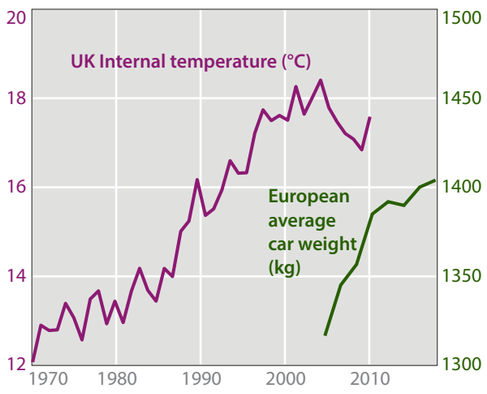


Figure 1.6: Energy demand (a) by sector (Mtoe) influenced by (b) car weight & internal temperature





use is compensated by an increase in other countries. Meanwhile, demand in other sectors is rising, driven, for example, by an increase in the weight of our cars and increased use of heating to raise internal temperatures in winter (Fig. 1.6b). With thirty years remaining to deliver zero emissions and global emissions still rising, we cannot risk waiting for a different energy system, so must have an inclusive public discussion about how we use energy.

2019 has seen a great rise in public concern about climate change, driven by science and growing evidence of changes occurring. So far, social protesters have called for dramatically increased awareness, while engaging in discussion about specific solutions has had less emphasis. However the only solutions available in the time remaining require some change of lifestyle. This report therefore aims to trigger that critical discussion. The report starts with a plan to reach zero emissions by 2050 using only technologies that are already mature today, to minimise the risk that we continue emitting beyond 2050. This is possible but requires some specific restraint in our lifestyles. Innovation can relieve this restraint so the report then presents an overview of the range of options for innovation in the way we use energy as well as how we generate it.

Global emissions are still rising and the need for action is urgent. This report aims to allow us to start an informed discussion about the options that really will deliver zero emissions by 2050.

Key Message: Global demand for energy is rising. In the UK our demand has fallen, but only because we have closed industry and now import goods elsewhere. Policy discussions have prioritised breakthrough technologies in the energy system, particularly carbon capture and storage, but it is at such an early stage of development that it won't reduce emissions significantly by 2050.

1.2 UK Energy System now and in 2050

Climate change is driven by greenhouse gas **E**missions. Most emissions arise from burning fossil fuels to create **E**nergy; some of our energy use is in the form of **E**lectricity. These three words beginning with "E" are often confused in public dialogue, but Fig. 1.7 separates them. Three quarters of global emissions (slightly more in the UK because we import 50% of our food) arise from the combustion of fossil-fuels (coal, gas and oil). Most coal and one third of gas is used in power stations to generate electricity. However, we also generate electricity by nuclear power and from renewable sources. The third column of the figure shows that nearly a half of the UK's current electricity supply is from non-emitting sources, of which nuclear power and the use of imported bio-energy pellets are most important.

Fig. 1.8 shows how the UK's energy supply has developed over the past twenty years. Total demand has fallen, due to the loss of industry shown in Fig. 1.6, but our use of oil and nuclear power has been relatively constant. (The data in both figures disguise the fact that over this period the UK's population has grown by 16% so we have improved the efficiency of our energy use by around 0.5% per year.) The other major change in the figure is the switch from coal to gas powered electricity generation which has reduced UK emissions significantly.

Fig. 1.9 extracts from Fig. 1.8 our generation of electricity – the numbers in this figure for 2018 correspond to those shown in Fig 1.7c – and divides them into emitting and non-emitting sources. This figure shows the UK making good progress in de-carbonising its current levels of electricity supply, and if the linear-trends in the figure continue, then

Figure 1.7: Emissions, Energy and Electricity in the UK

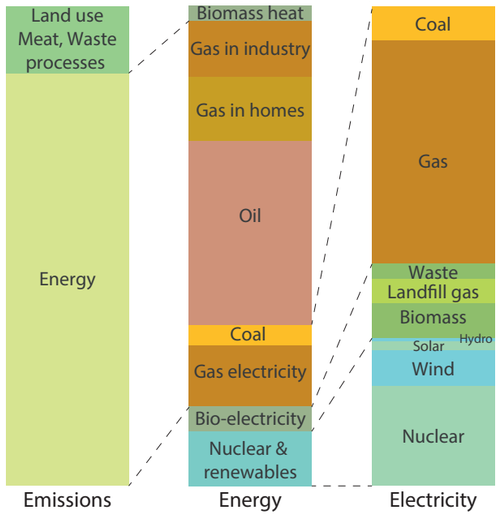
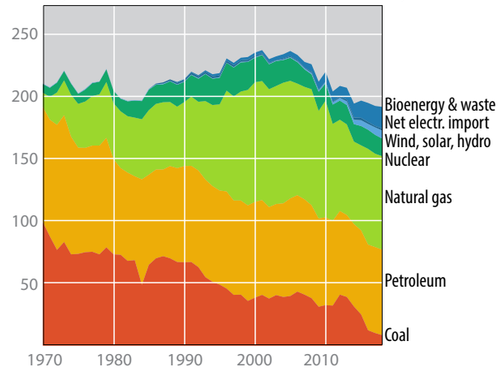


Figure 1.8: UK Primary Energy supply (Mtoe/yr)



by 2050, the UK can be expected to generate around 580 TWh of electricity without emissions. This is the figure shown on Fig 1.1 at the beginning of this chapter.

If we can manage our electricity distribution system and find ways to store electricity from windy/sunny times to be available at still/dull times this suggests that by 2050 we will have around 60% more electricity available than today, all from non-emitting sources. Physically, although the Hinckley C Nuclear Plant will probably by completed by 2030, delivering this increase will largely come from increasing wind-generation. To meet this growth from offshore wind would require an addition of around 4.5 GW of generation capacity each year of the next 2 decades (allowing time for them to be fully operational by 2050). By comparison, the Crown Estate have just launched a process to award 7-8.5 GW of new seabed leases over the next 2 years, but the Offshore Wind Sector Deal expects Government support for the delivery of only 2 GW/year through the 2020s.

Figure 1.9: UK Electricity generation (TWh/year)

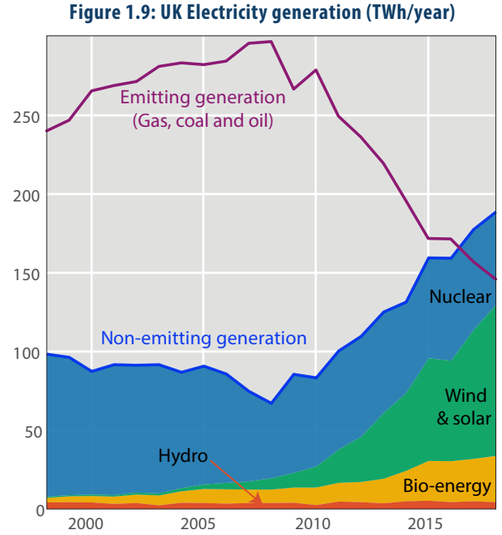
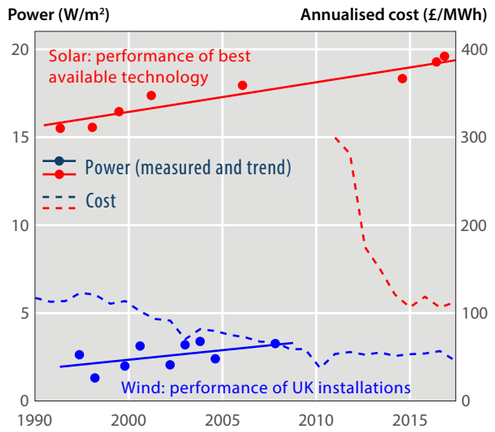


Figure 1.10: Development of wind and solar power



Meanwhile Fig 1.10 shows how the two options for on-shore generation, wind-turbines and solar power, are developing. Both technologies are becoming cheaper, although the amount of power generated from each unit of land is increasing only slowly. Replacing existing on-shore wind turbines with much taller models could increase total generation by 50%. Increasing solar generation depends on the commitment of area, but is plausible: if every south-facing roof in the UK were entirely covered in high-grade solar cells, this would contribute around 80TWh per year

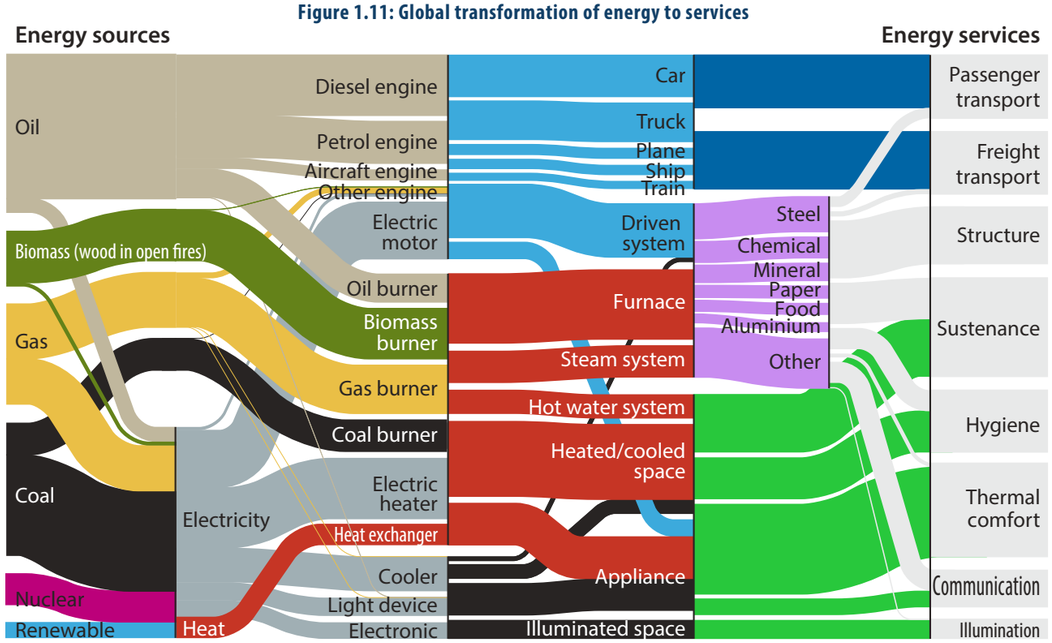
Fig. 1.7 also shows a range of bio-energy sources contributing to the UK's energy supply. All these supplies are combusted, leading to the release of CO_2, but because the fuel derives from plants, these releases form part of the normal cycle so do not accelerate climate change. Waste policy has been a success in UK mitigation since 1990, with organic waste separated and largely processed in anaerobic digestors to produce methane for electricity. However, this source is unlikely to increase further. Meanwhile, bio-energy derived directly from new plant growth is in competition with the use of biomass for food so unlikely to increase (see box story on p13).

This discussion suggests that, using today's technologies and with plausible rates of expansion, the UK will in a zero-emissions 2050 have an energy supply entirely comprising electricity with about 60% more than generated than we have today.

How much of the benefit of all of today's use of energy will we be able to enjoy without any fossil fuels, but with 60% more electricity? At first sight, this sounds like a significant reduction - Fig. 1.7 showed that today, electricity provides only about one third of our total energy needs, so apparently we would need a 200% increase in electricity output? In fact this isn't the case, because the final conversion of electricity into heat or rotation is very efficient compared to the fossil fuel equivalents.

If the UK is to run entirely on electricity, then all devices currently powered with fossil-fuels must be replaced by electrical equivalents. Fig. 1.11 presents a view of how energy is used globally. (We don't currently have an equivalent of this for the UK, but the UK is likely to

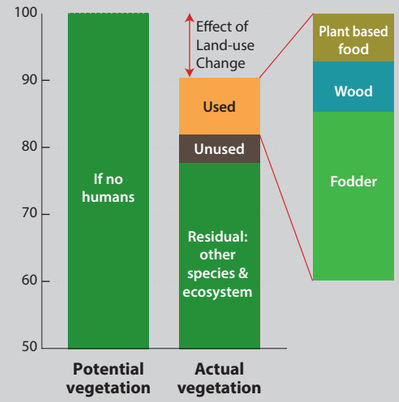
Figure 1.11: Global transformation of energy to services



What's the problem with bio-energy?

The world's poorest people stay warm and cook with wood burnt on open furnaces, and this energy source shows up significantly in the global energy supplies of Fig. 1.11. Could we use modern technology to harness even more biomass to make other fuels, such as biodiesel or kerosene? Fig 1.12 reveals that more than 20% of the world's total annual harvest of new biomass is already 'appropriated' by humans for wood, food and fodder. This annual harvest is the fundamental source of habitat and food for all non-aquatic species. Any further appropriation by humans is likely to be dangerously harmful to other species and the effect of deforestation rates is already a major contributor to the emissions in fig. 2.10. This evidence suggests that modern bio-fuels are incompatible with any wider sustainability of life on earth.

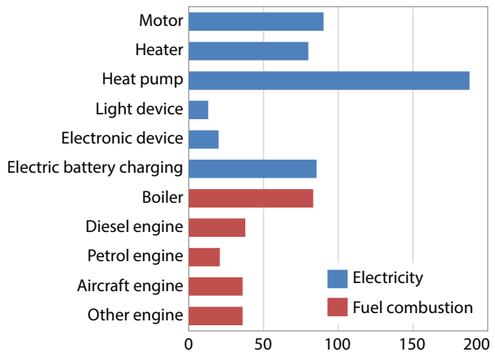
Figure 1.12: Human appropriation of biomass



be similar, although with less industrial use, due to our dependence on imports.) The widths of the lines in the figure are proportional to energy use, and any vertical cut through the diagram could be converted into a pie-chart of all the world's energy use. In effect Fig. 1.11 shows six connected pie-charts, each breaking out the statistics of all the world's energy use into different categories.

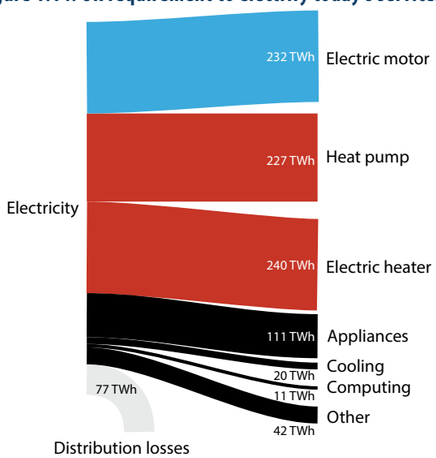
The figure shows that most energy is used in engines, motors, burners and heaters to create motion or heat. To estimate the electricity required if all of these devices are replaced, we use the average efficiencies presented in Fig. 1.13: for example, we know how much power is currently delivered in the UK's cars by petrol engines, so can use Fig. 1.13 to predict how much electricity would be required to provide the same power from electric motors. Combining this conversion with an estimated 11% population growth, leads to our prediction that we would need 960 TWh of electricity by 2050. (A terawatt hour, Twh, is a thousand million kilowatt hours - the unit normally used in UK energy bills.) The final requirement for electricity is split between motion, heating and appliances as shown in Fig 1.14.

Figure 1.13: Efficiency of enegy conversion devices (%)



If the UK is fully electrified by 2050, and we used the same final services as today, our demand for energy as electricity will be 960 TWh. However, based on a linear projection of the rate at which we have expanded our non-emitting electricity supply in the past 10 years, we estimate that we will have just 580 TWh available. Therefore, our commitment to Absolute Zero emissions in 2050 requires a restraint in our use of energy to around 60% of today's levels.

Figure 1.14: UK requirement to electrify today's services



Key Message: If we only used electricity, delivering all the transport, heat and goods we use in the UK would require 3x more electricity than we use today. If we expand renewables as fast as we can, we could deliver about 60% of this requirement with zero emissions in 2050. Therefore in 2050 we must plan to use 40% less energy than we use today, and all of it must be electric.

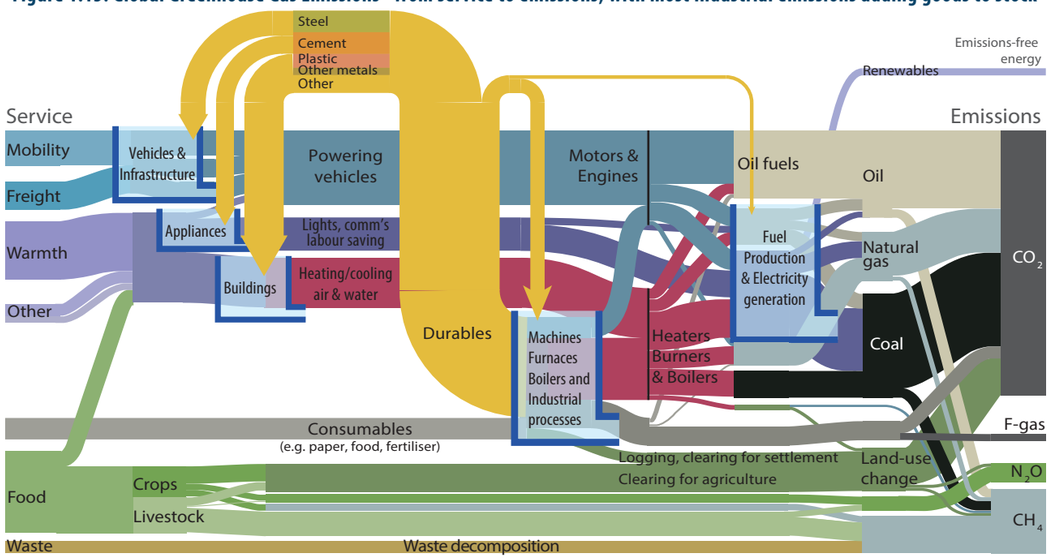
1.3 Zero emissions in the UK in 2050

In addition to restraining our energy demand to 60% of current levels, meeting our legal commitment to zero emissions will require that we phase out any energy using activities that cannot be electrified and any sources of emissions beyond fossil-fuel combustion. Planning for this requires that we make a collective decision about the scope of our responsibility. The UK's Climate Change Act was written to make commitments based solely on emissions that occur on UK territory. However, this excludes international aviation and shipping and our net imports of goods. As a result, it appears to be a success for UK climate policy when we shut UK industry and instead import goods – even though this will not reduce global emissions, and may often increase them if the closed UK processes were more efficient. Although these limitations were helpful in passing the Climate Change Act into law, they now look morally questionable, and they also fail to create the stimulus to innovation and growth in UK businesses and industries fit for a zero emissions future. This report therefore assumes that the UK should be responsible for the emissions of all its consumption.

Fig. 1.15 shows an analysis of all global greenhouse gas emissions, using a format similar to Fig. 1.11. In this case, the final services that drive the activities that cause emissions are shown at the left of the diagram, leading to the greenhouse gases on the right side of the diagram which cause global warming. The yellow-loop in the middle of the figure demonstrates that most industrial emissions are associated with producing the buildings, vehicles and other equipment which provide final services from energy, but which themselves require energy in production. This is important because most of this year's industrial output is to produce equipment (durables) that will last for several years. The services provided in one year therefore depend on the accumulation of a stock of goods made in previous years - and this long-lasting stock limits the rate at which change can be made to our total emissions. For example, if cars last on average for 15 years, then to ensure that all cars are electric in 2050, the last non-electric car must be sold no later than 2034. As with Fig. 1.11, Fig. 1.15 is based on global data - again to reflect the consequences of UK consumption, rather than its "territorial" emissions.

The top three quarters of this figure demonstrate the emissions consequences of our use of energy. The two critical forms of equipment that cannot be electrified with known technology are aeroplanes and ships. Although Solar-Impulse 2, a single-seater solar-powered electric aeroplane circumnavigated the Earth in 2016, it is difficult to scale up solar-powered aeroplanes due to the slow rates of improvement in of solar cell output put unit of area shown in Fig. 1.10. Meanwhile battery-powered flight is inhibited by the high weight of batteries, bio-fuel substitutes for Kerosene face the same competition for land with food as described in section 1.2 and there are no other ready and appropriate technologies for energy storage. As a result, under the constraint of planning for zero emissions with known technologies, all flying must be phased out by 2050 until new forms of energy storage can be created. At present we also have no electric merchant ships. There isn't space to have enough solar cells on a ship to generate enough energy to propel it, and as yet there has been no attempt to build a battery powered container

Figure 1.15: Global Greenhouse Gas Emissions - from service to emissions, with most industrial emissions adding goods to stock



ship. Nuclear powered naval ships operate, but without any experience of their use for freight, we cannot safely assume that nuclear shipping will operate at any scale in 2050. This is a serious challenge: with today's technologies, all ship-based trade must be phased out by 2050.

Fig 1.15 further reveals that the two key sources of non-energy related emissions are in agriculture and industrial processes. Agricultural emissions arise primarily from ruminant animals – in particular cows and sheep – which digest grass in the first of their two stomachs in a process that releases methane and from land-use change. Converting forestry to agricultural land leads to the release of the carbon stored in the forest and the loss of future carbon storage as the trees grow. In addition, ploughing the land releases carbon stored in the soil, and using Nitrogen based fertilisers to stimulate plant growth leads to further emissions. The motivation for this conversion of forestry land is to increase food production, but is greatly exacerbated by the demand for meat eating. Growing grain and other feed for cows, pigs and sheep is exceptionally inefficient, as up to 80 times more grain is required to create the same calories for a meal of meat as for a meal made from the original grain. As a result, our commitment to zero emissions in 2050 requires that we refrain from eating beef and lamb.

Three industrial processes contribute significant emissions beyond those related to energy. Blast furnaces making steel from iron ore and coke release carbon dioxide, and half of the emissions from current cement production come from the chemical reaction as limestone is calcined to become clinker. There are no alternative processes available to deliver these materials, and although old steel can be recycled efficiently in electric arc furnaces, there are no emissions-free alternatives to cement being produced at any scale. As a result, a zero-emissions economy in 2050 will have no cement-based mortar or concrete, and no new steel. The absence of cement is the greatest single challenge in delivering Absolute Zero, as it is currently essential to delivering infrastructure, buildings and new energy technologies.

The final source of direct industrial emissions is the group of "F-gases" which have diverse uses, including as refrigerants, solvents, sealants and in creating foams. It may be possible to continue some of these applications beyond 2050 if the gases are contained during use and at the end of product life.

Delivering Absolute Zero in thirty years with today's technologies is possible. Our energy supply will be 40% less than today, and solely in the form of electricity, but apart from flight and shipping, all other energy applications can be electrified. Socially motivated action is leading some change in both travel and diet. The most challenging restraint is on the bulk materials used in construction, in particular in the absence of cement, which will constrain the deployment of new energy supplies and economic development which depends on building.

However, despite these restraints, the most striking feature of this analysis is how many features of today's lifestyles are unaffected. Many of the leisure and social activities we most enjoy can continue with little change, many forms of work in service sectors will flourish, and the transition required will also lead to substantial opportunities for growth, for example in renewable electricity supply and distribution, in building retrofit, in electric power and heat, in domestic travel, material conservation, plant-based diets and electrified transport. Delivering Absolute Zero within thirty years with today's technologies requires restraint but not despair and of course any innovation that expands service delivery without emissions will relieve the required restraint. That's the theme of the second chapter of this report.

Key Message: In addition to reducing our energy demand, delivering zero emissions with today's technologies requires the phasing out of flying, shipping, lamb and beef, blast-furnace steel and cement. Of these, shipping is currently crucial to our well-being - we import 50% of our food - and we don't know how to build new buildings or install renewables without cement. The need for this restraint will be relieved as innovation is deployed but many of our most valued activities can continue and expand, and Absolute Zero creates opportunities for growth in many areas.

2. Innovations to make more use of less energy

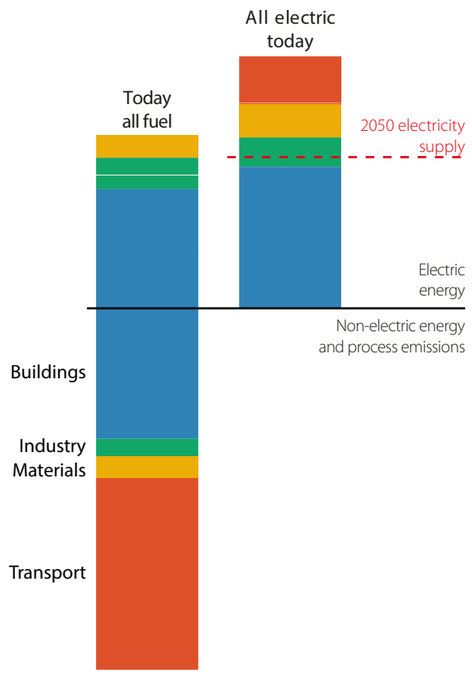
Key Message: With incremental changes to our habits and technologies, there are multiple options for living just as well as we do today, with 60% of the energy. With electric heat pumps and better insulation we can stay just as warm. With smaller electric cars we can keep moving, and by using materials better, we can make buildings and goods compatible with our zero emissions law.

This chapter starts from the analysis of electricification in chapter 1, summarised in Fig. 2.1: below the line, all of today's non-electric uses of energy must be electrified. Any activities that lead to emissions regardless of energy source or that cannot be electrified must be phased out. If we electrify all remaining activities with today's technologies, we require the amount of electricity shown in the second column - but we'll only have 60% of that amount available. For each of the sectors in Fig. 2.1, we therefore look at all the options for a more efficient future.

Section 2.1. focuses on the way we use energy directly - in buildings and vehicles - and on the way we source our food. Sections 2.2-2.4 explore how we make things - firstly looking at how we produce materials, which is what drives most of today's industrial emissions, and then in how we use them in construction and manufacturing. It turns out that we are already very efficient in our use of energy when making materials, but wasteful in the way we use the materials - so there are plenty of options for living well while using half as much material for twice as long.

For completeness, in section 2.5 we survey the "breakthrough technologies" that are unlikely to be significant by 2050, but could expand afterwards.

Figure 2.1: Absolute Zero overview



2.1 Products in-use and consumables

In the UK, the use of final products and consumables accounts for almost three quarters of current annual emissions. 12% of UK emissions come from domestic food production, waste disposal and land use changes, but two thirds are produced by our use of vehicles and buildings. These mostly come from road transport and heating in buildings, but to what extent can innovation help reduce these emissions to zero?

Using energy in buildings

Fig. 2.2 shows that most energy uses in buildings are for heating air (space) and water, mostly by combustion of gas in individual boilers in each building. Absolute Zero emissions requires a complete electrification of energy uses in buildings. Although appliances and lighting are already electric, space and water heating must change.

Heat pumps, based on principles similar to the familiar domestic fridge - but in reverse, offer a viable alternative to gas boilers. Since heat pumps are around four times more efficient than direct heat of combustion, complete deployment of best-practice heat pumps could save approximately 80% of current energy demand for heating. Heat pumps can be used in two forms: as a direct replacement for a gas-boiler they can provide hot water for a conventional radiator system. However, the best use of heat pumps is with ducted air heating - which requires a more intrusive modification of a building, but saves more energy. Deploying heat pumps would almost double the demand for electricity in buildings from current levels, so further interventions to reduce the demand for heating are also important.

New buildings are much more efficient than old Victorian houses still in use today — better insulation and design result in much smaller heating requirements. However, the turnover of the UK's building stock is very slow - we like old buildings - so refurbishment of old houses is important. Already, we have made substantial efforts to retrofit double glazed windows and to install high quality insulation in roofs and attics, and this could be completed to ever higher-standards to reduce national energy demand for heating.

For new build homes, Passive designs which only use the sun for heating, and need electricity only for ventilation, lighting and appliances are now well established. Until 2015, the UK's zero-carbon homes standards promoted this form of design, which is applied rigorously in Sweden, and at current rates of building, would affect 20% of the UK's housing if enforced now. The cost of houses built to the Passive standard is approximately 8-10% more than standard construction, and the thick walls required slightly reduce the available internal space, in return for zero energy bills.

Fig. 2.3 summarises the options for operating buildings under the conditions of Absolute Zero: whatever happens we must electrify all heating. We could then either use the heating for 60% of the time we use it today, or apply other incremental changes in building design to maintain today's comfort with 60% of the energy input.

Figure 2.2: Energy use in buildings

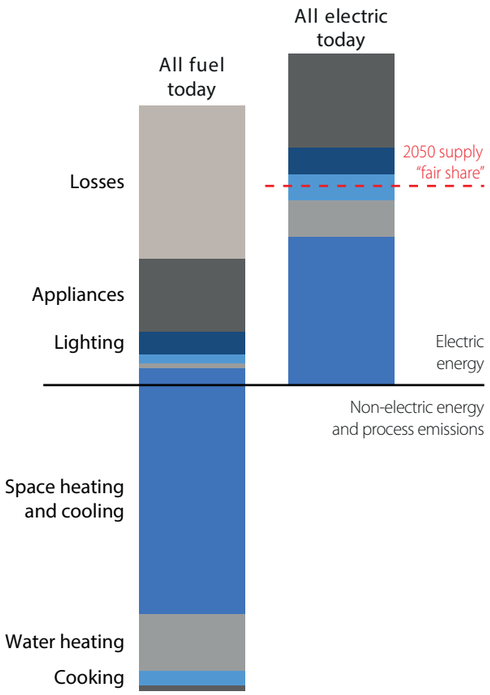
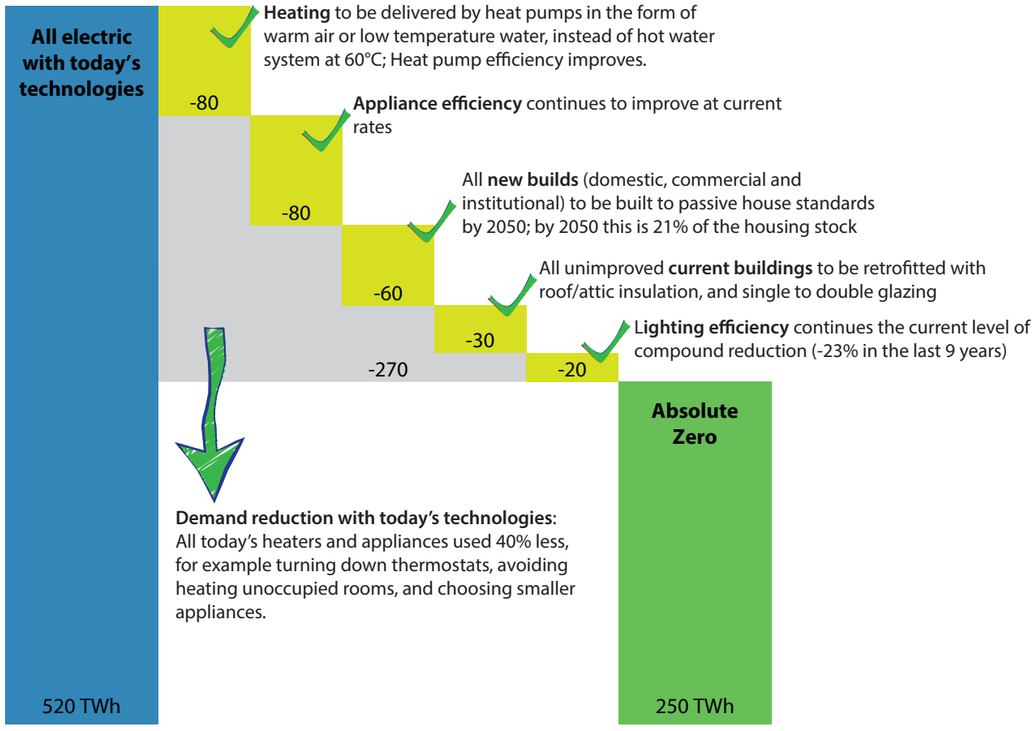


Figure 2.3: Reducing energy use in buildings with incremental technologies or reducing demand with today's technology



Using energy in transport

Fig. 2.4 shows that almost all of today's transport involves the direct combustion of fossil fuels in the vehicle, with only 1% of transport powered by electricity, in electric trains. Without technology options to replace aeroplanes and ships with electric equivalents, the second column of the figure assumes that these modes have been phased out in thirty years, so the electricity available for transport can be divided between rail and road vehicles.

Fig. 2.5 demonstrates the opportunity for energy saving through adjusting the way we travel. The figure shows both the energy and emissions consequences of a person travelling a kilometre by different modes: these two figures are closely correlated except for flight, where the emissions at high altitude cause additional warming effects. The figure underlines how important it is to stop flying - its' the most emitting form of transport and we use planes to travel the longest distances. A typical international plane travels at around 900km/hour, so flying in economy class equates to 180kgCO_{2e} per person per hour (double in business class, quadruple in first class, due to the floor area occupied.) Flying for ~30 hours per year is thus equal to a typical UK citizen's annual emissions.

The key strategies to reduce energy use in transport depend on the form of journey. Short distance travelling involves frequent stops and restarts, so a substantial

Figure 2.4: Energy use in transport

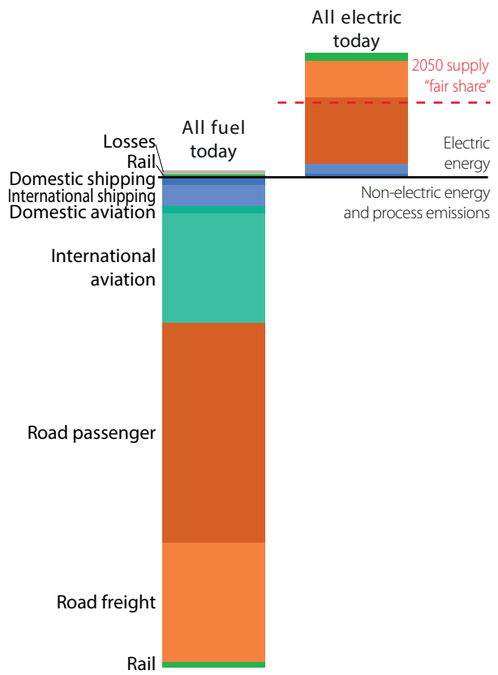
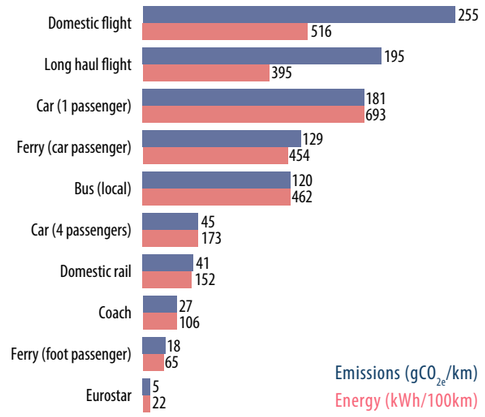


Figure 2.5: "Mode shift" for personal transport



share of energy is used to accelerate a vehicle and its contents. As a result, reducing the weight of the vehicle and travelling less become key strategies to reduce energy demand. At present UK cars are on average used with 1.8 people inside, but weigh around 1,400 kg, which is ~12 times more than the passengers, so almost all petrol is used to move the car not the people. Fig. 2.6 illustrates how reducing the ratio of the weight of the vehicle to the weight of the passengers trades off with distance travelled and energy used. Regenerative braking offers a technological opportunity to recapture some of the energy used in accelerating vehicles, and is under active development.

For long-distance travelling most energy is used to overcome air resistance, so the key to reducing energy demand is to reduce top speeds (aerodynamic forces increase with speed squared) and drag by using long and thin vehicles — trains. Rail transport is thus the most efficient transport mode for long-distance travelling, and if a higher share of trips is made by train rather than car,

Figure 2.6: Car travel - trading weight and distance

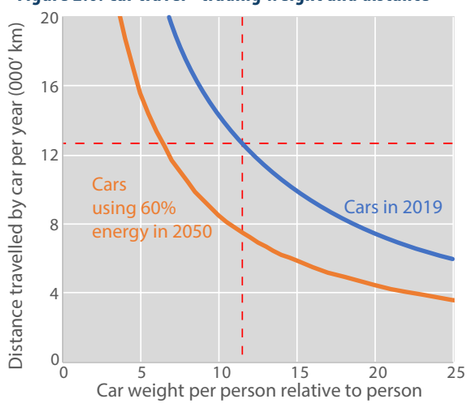
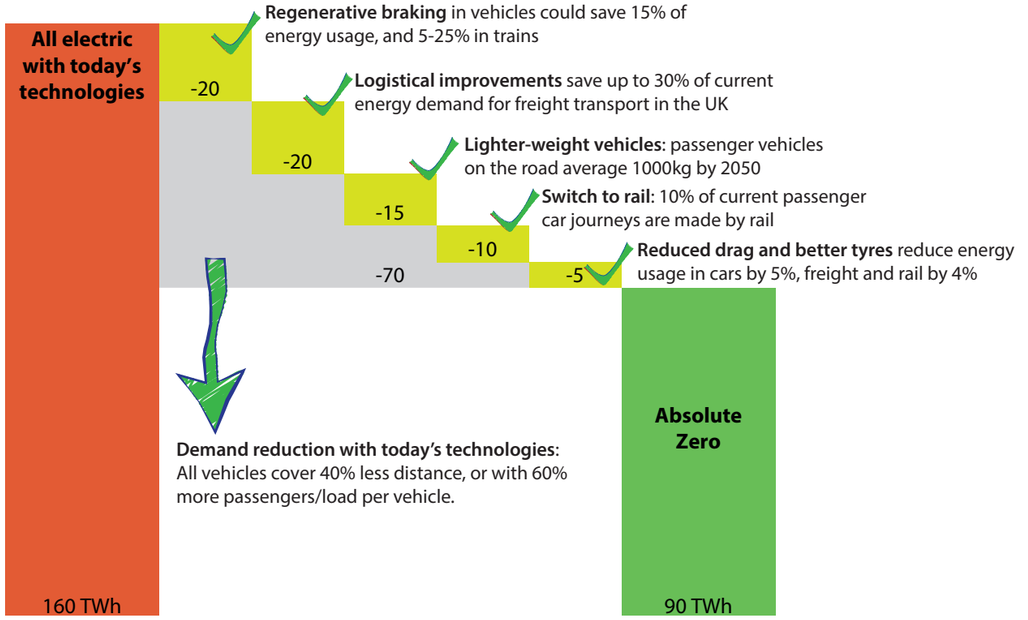


Figure 2.7: Reducing energy use in transport with incremental technologies or reducing demand with today's technology



substantial energy savings can be achieved without loss of mileage. A full electric train can move people using 40 times less energy per passenger than a single-user car.

Other modes of transport can also reduce energy demand in transport. For example, in the Netherlands, approximately 20% of all distance travelled is by bicycle, compared to only 1% in the UK.

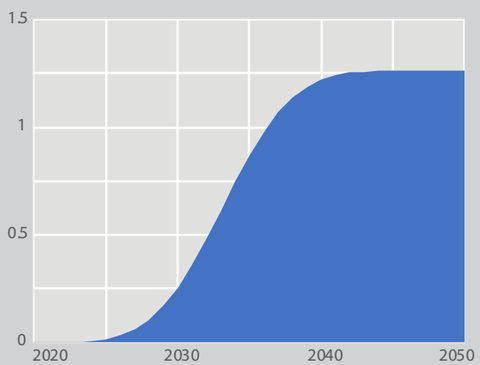
Although there are opportunities to reduce energy demand by mode shift in freight transport, substantial savings could also be achieved by logistical improvements. Up to 30% of energy demand in freight could be saved with an optimised location of distribution centres and with the creation of new collaborative networks to promote co-loading. Technology to facilitate the implementation of these logistical strategies already exists or is expected to become available over the next five years, although this also requires new corporate partnerships.

Fig. 2.7 summarises the options for electrifying UK transport and using 60% of the energy. Either vehicles are modified - with regenerative braking, reduced drag and rolling resistance (better tyres), and weight reductions, or we can choose to use them less - through ride-sharing, better freight management, or an overall reduction in distance travelled.

Can we make & recycle enough batteries?

Lithium battery manufacturing requires a wide range of metals, most of which only exist in nature at very low concentrations. Cobalt is one of the most valuable and is currently essential to the stability and lifetime of batteries. If new car sales are to be completely electric within 5 years, we will need to make 50 million batteries by 2050, just in the UK. Most cobalt production is obtained as a by-product of nickel and copper mining, so could only expand if demand for these materials expand in proportion. Batteries can be recycled, but separating the materials in them is difficult and mining new metals is tehrefore currently cheaper than recycling. There is no simple route to recycle lithium batteries at present, but the surge in old batteries shown in Figure 2.8 should trigger innovation to address this.

Figure 2.8: Estimated volumes of electric car batteries reaching their end-of-life in the UK (millions/yr)



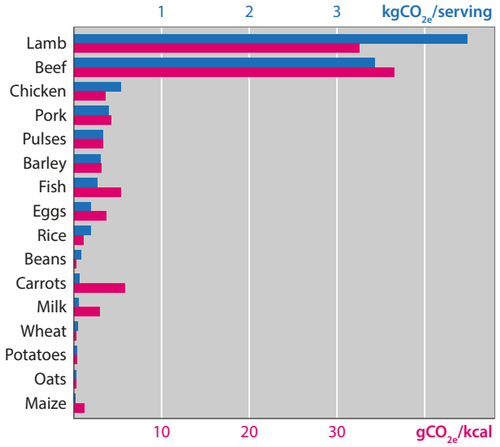
Land-use, food and waste

Fig. 1.15 demonstrated that around a quarter of global emissions arise from good production and the decomposition of organic wastes. The UK figures in Fig. 1.7 show this fraction being closer to one sixth, which reflects the fact that the UK imports around half of its food. Fig 2.10 provides more detail on these non-energy and non-industrial emissions.

As waste biomass breaks down to compost, it releases either carbon dioxide (if the biomass is in contact with air) or methane, which is a much more potent greenhouse gas and is the main driver of the emissions from waste decomposition. However, methane is the gas we use in cooking or in gas fired electricity generation, and the greatest success of recent UK climate policy has been to reduce these emissions significantly. Households across the UK now expect to discard organic wastes in their green bins, which are collected as the feedstock for anaerobic digesters which generate methane for energy production as shown in Fig. 1.7. As a result, UK landfill methane emissions have reduced by more than 50% since 1990 and will be close to zero by 2050.

The other major sources of emissions in Fig. 2.10 are largely related to ruminant animals – cows and sheep – grown for meat and dairy consumption. Ruminants digest grass in their first stomach, leading to methane emissions (enteric fermentation) while also releasing methane with their manure. In parallel, rising global demand for food is driving demand for increased biomass production, around half of which is to feed animals and in turn this drives forestry clearance. Trees are a substantial store of carbon, so clearance increases emissions either as CO_2 if the wood is burnt, or more damagingly, as methane if left to rot. The clear implication of Fig 2.10 is that eating lamb and beef will be incompatible with Absolute Zero.

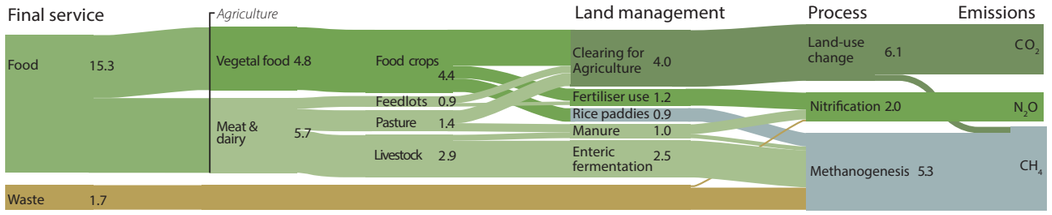
Figure 2.9: Emissions intensities of food



This message is underlined in Fig. 2.9 which gives an estimate of the emissions associated with a meal with typical portions of different diets. The figure demonstrates that a vegetarian meal isn't emissions free, and a meat-based meal (with pork or chicken) may not have much more impact than one based on pulses. However, the ruminant meats stand out so are a priority action in moving towards Absolute Zero.

The market for vegetarian food is currently growing rapidly, as rising social concern about emissions has motivated many individuals to switch to a more plant-based diet. There is significant potential for innovation in extending and developing new manufactured meat substitutes. Research has also begun to examine whether alternative feeds could eliminate ruminant emissions, but this is not yet mature.

Figure 2.10: Global emissions from agriculture, and organic waste (total in 2010: 17 Gt CO_{2e})



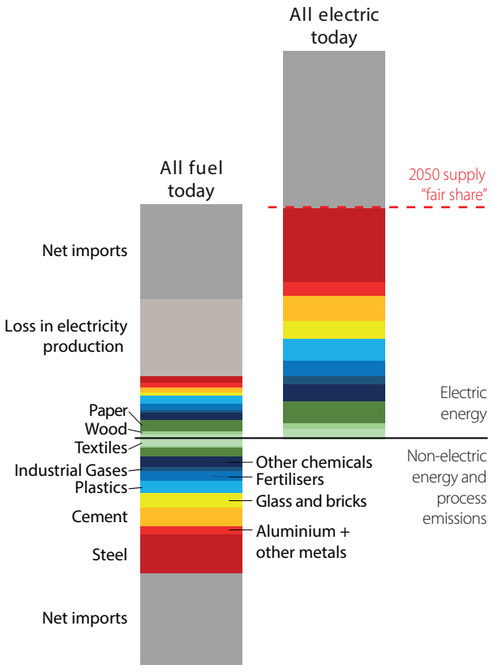
Key Message: Most of today's UK lifestyles can continue and grow within the target of Absolute Zero. Changing the way we travel (in particular not flying, and making better use of wheeled vehicles), stay warm (using electric heat pumps instead of gas boilers) and eat (cutting out lamb and beef) are the most important changes that we would notice. In parallel, small changes in the design of buildings and vehicles can make them more efficient. However the biggest challenge revealed in this section is the use of shipping for freight: at the moment we have no alternatives.

2.2 Materials and Resources

The implications of the analysis of chapter 1 for material production are summarised in Fig. 2.11. The UK imports much of our material requirement - either as materials, components or finished goods - so around half of the impact of our consumption today leads to the release of greenhouse gas emissions in other countries. Of the bulk materials that drive most industrial emissions, paper and aluminium production are the only two for which electricity is the dominant energy source. The processes that make materials can nearly all be electrified, but the challenge to Absolute Zero is to deal with the production processes that inevitably lead to emissions. Blast furnace steel can be replaced by steel recycled in electric furnaces, and this leads to the expansion of electricity for steel production shown in the figure. However, we currently have no means to avoid the emissions of cement production - even if the process were electrified - because the chemical reaction that converts limestone into cement inevitably releases carbon dioxide. Without innovation, we will be unable to use concrete or mortar - the two forms in which we generally use cement - but because this is so difficult to envisage, we have allowed some electric supply for the production of cement alternatives.

Starting from cement, this section explores the opportunity for innovation to expand the available supply of materials within Absolute Zero emissions.

Figure 2.11: Energy use in producing materials



Cement

Cement hardens when mixed with water because the solid products of the reaction (called hydrates) have a higher volume than the cement powder and thus form a solid skeleton. Only a few elements in the periodic table have this property and are also widely found in the Earth's crust. The elements available in the earth's continental crust with an abundance higher than 1% are silica (60.6%), alumina (16.9%), iron oxide (6.7%), lime (6.4%), magnesia (4.7%), sodium oxide (3.1%) and potassium oxide (1.10%). Of these, Portland cement mainly uses calcium and silica, with aluminium, iron, calcium and sulphur also playing a minor role. Calcium and aluminium together can form a heat-resistant cement used in refractory applications. Magnesium, sulphur and aluminate can also work together as a cement, but attempts at making a reliable product from them have proven unsatisfactory. Iron does not form hydrates with a high volume. Thus, the key ingredient to Portland cement is calcium, which is found mostly in the form of limestone (or calcium carbonate), as the fossilised remains of micro-organisms which have combined CO_2 and calcium to form shells for billions of years.

60% of emissions from cement production arise from the chemical reaction of calcination in which limestone is converted to clinker - the precursor of cement. The remaining emissions are due to the combustion of fossil fuels (and waste materials) in kilns. Although heating processes may be electrified in the future, process emissions from calcination would be unavoidable, unless alternative sources of calcium oxide are found to replace limestone in cement production. Currently it appears to be impossible to produce cement with Absolute Zero emissions. Technology innovation on the alternatives to calcination and reconfiguration of the cement industry could enable zero emissions in cement production. However, any innovation in these processes would probably require a substantial reduction in cement demand from current levels.

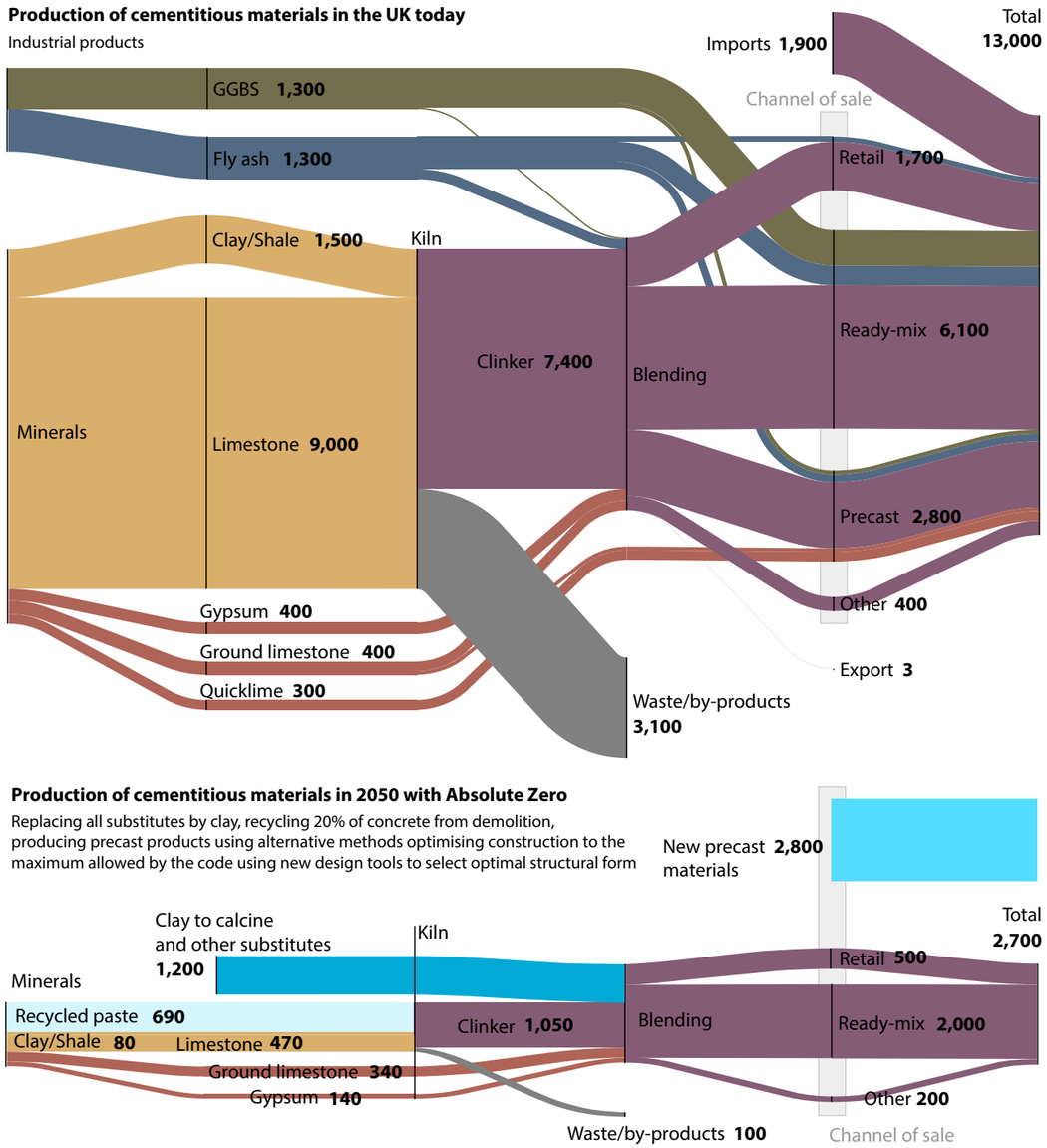
Currently, the construction industry makes use of many substitute materials to reduce the total demand for cement: both fly ash a by-product of burning coal, and ground granulated blast furnace slag, a by-product of the steel industry are used. Together, they reduce the need for pure Portland cement by about 20%. However, in a zero-carbon world, neither of these products would be available - as coal combustion and blast furnaces would not be possible - which leads to an increase in the need for new cement.

It is possible to produce pre-cast products (bricks, blocks, or slabs) with zero or even negative emissions, whether

using micro-organisms which transform CO_2 to calcite or through bubbling CO_2 through magnesium sulfo-aluminate cement-based mixes. These could satisfy some of the construction industry's needs, but we have no alternative binders to replace Portland cement on construction sites. It is often claimed that geopolymers (fly ash or slag which react to form hydrates in the presence of alkalis) could replace Portland cement. However, this is not an option in a zero-carbon world because the base materials for geopolymer come from highly emitting industrial processes (burning coal and coking steel) which will not continue.

Pre-cast products could replace at most 14% of current uses of cement, but without binders, they could not be used for foundations or repairs even of critical infrastructure. One of the most common structural elements in today's commercial buildings, the flat slab which is cast in place from liquid concrete brought to site in mixer trucks and used to build floors, would disappear: the only available option would be pre-cast elements, but these could not be finished, as they are now, with a thin layer of concrete (called a screed). A currently popular construction method, composite construction using thin concrete slabs poured over corrugated steel sheets and beams, would also be impossible, despite being more materially efficient than the reinforced concrete flat slab.

Figure 2.12: Production of cementitious materials in the UK and with innovation for zero emissions in 2050 (kT/yr)



There are two complementary paths that might lead to reducing the emissions from cement production.

Firstly, there may be new sources of cement replacement, and new low-carbon feeds for the production. A promising source of cement replacement is kaolinite-rich clay. Kaolinite is an oxide of aluminium and silicium, which when calcined at 850 C transforms into metakaolin which is an amorphous, reactive product. Because of the lower calcination temperature, this material is about half as energy intensive as Portland cement. It has the interesting property that it can react with raw limestone to form hydrates, as well as substitute cement. Thus substitution levels of up to 65% can be achieved without lowering strength. In the UK, waste from kaolinite mining in Wales can provide a good source of clay to calcine. London clay is of a poorer quality but could still be used if the strength requirements of new construction were lowered.

The second path to producing zero-carbon cement is to eliminate limestone from the feed of cement. An abundant source of calcium which is not carbonated is concrete demolition waste. Current best practice suggests that approximately 30% of the limestone feed of a cement kiln can be replaced by concrete demolition waste. This limit is due to the presence of the concrete aggregates, but if a separation process was established, and only the cement paste from concrete demolition waste was used, then it could be possible to produce cement without chemical process emissions.

The amount of demolition waste available yearly in the UK could cover an important fraction of our yearly needs, provided heroic efforts were made to make good use of this available source of materials. 30 Mt of demolition waste is produced yearly (2007 value from the National Federation of Demolition Contractors), 59% of which is concrete of which 20% is cement paste. An 80% yield in separating aggregates from paste would then provide 3 Mt of low carbon feed for the kilns to produce new cement.

Fig. 2.12 illustrates a summary of this narrative, comparing today's UK requirements for cement (or more generally, "cementitious material") in the upper picture, and the maximum possible supply we can envisage within the constraints of Absolute Zero in the lower picture. Section 2.3 will consider the opportunities to deliver construction with the 75% reduction in cement production implied by this figure.

Finally, there are many possible options for structural elements not using concrete and steel, including rammed earth, straw-bale (ModCell), hemp-lime, engineered bamboo and timber (natural or engineered). Often, these materials claim superior carbon credentials, which may be exaggerated, but they also come with enhanced building-physics attributes, including insulation, hygrothermal and indoor air quality benefits. These could be used to substitute concrete in some applications, but would require different design processes and choices of architectural forms.

Steel

Recycling steel in electric arc furnaces powered by renewably generated electricity could supply most of our needs for steel, as it already does in the US. Almost all steel is recycled already (the exception is where steel is used underground, in foundations or pipework) and as Fig. 2.13 shows, the average life of steel-intensive goods is around 35-40 years. The amount of scrap steel available globally for recycling in 2050 will therefore be approximately equal to what was produced in 2010. Fig. 2.14 shows how the balance of global steel production can evolve in the next 30 years to be compatible with Absolute Zero: blast furnace steel making, which inevitably leads to the emissions of greenhouse gas due to the chemical reaction involved in extracting pure iron from iron ore using the carbon in coal, must reduce to zero. Meanwhile, recycling which happens in electric arc furnaces could be powered by renewable electricity to be (virtually) emissions free, and can expand with the growing availability of steel for recycling. Even without action on climate change, the amount of scrap steel available globally for recycling will treble by 2050. In order to meet the requirements of Absolute Zero, this valuable resource can be the only feedstock, as there is currently no alternative technology for producing steel from iron ore without emissions.

Figure 2.13: Life expectancy of steel by application

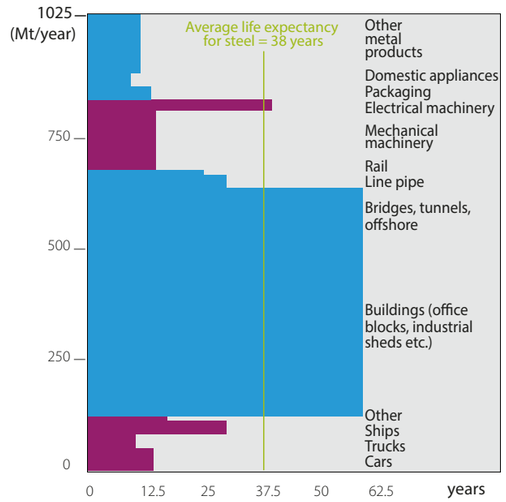
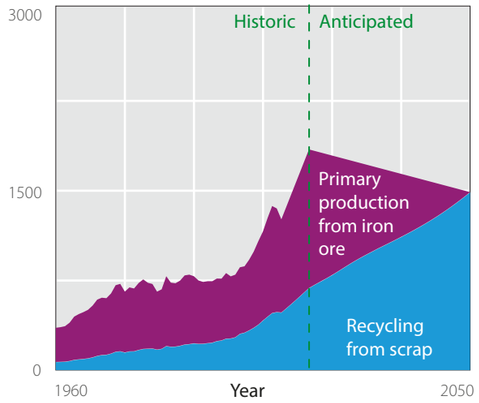


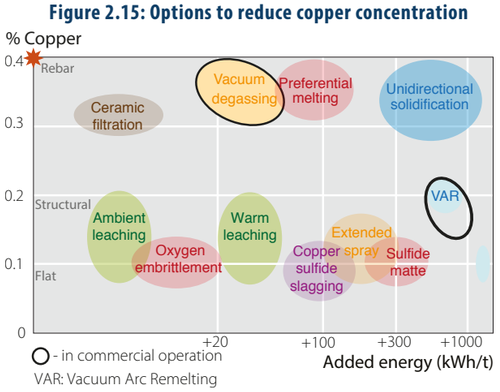
Figure 2.14: Global steel output in Absolute Zero (Mt/yr)



Recycled steel can have the same quality as blast furnace steel. In fact, some of the highest quality aerospace grades of steel used in the UK are made in Rotherham by recycling. However, the quality depends on the mix of metals supplied to the electric arc furnace, and is degraded in the presence of any significant quantity of tin or copper. Tin enters the steel recycling stream because of the use of tin-plate to make food cans, but this is relatively easily managed: these cans can be separated from other end-of-life steel and a mature process already operates at scale to separate the tin from the steel.

Copper is more of a problem in steel recycling, because current waste management involves shredding used cars and domestic appliances to separate metal from other materials, and these products contain many electric motors and associated wiring made from copper. There is a rich field of opportunity in responding to this problem, which could include: removing motors and wiring prior to shredding; improved separation of metals after shredding; metallurgical processes to remove copper from the liquid metal created by the electric arc furnace; developing new downstream processes to cope with copper contamination in the steel; eliminating copper for example by substituting it with aluminium. Fig. 2.15 presents a survey of metallurgical processes for reducing copper concentrations in liquid steel, from 0.4% (a typical value today for average UK steel scrap recycling) to around 0.1% (the threshold for higher quality applications such as car bodies) as a function of energy input. The high grade steels made in Rotherham are purified with vacuum arc remelting, with high energy (and therefore financial) cost, but the figure demonstrates how many other opportunities could be developed given the motivation provided by Absolute Zero.

Figure 2.15: Options to reduce copper concentration



Steel production is extraordinarily energy-efficient, and consequently steel is remarkably cheap. As a result, it is used wastefully, and in most applications we could deliver the same end-user service from half the amount of steel used for twice as long – i.e. requiring only 25% of annual steel production. This strategy of material efficiency depends on practices in construction and manufacturing so is discussed further in sections 2.3 and 2.4.

Non-ferrous metals

The production of non-ferrous metals is already almost completely electrified. The most notable example is aluminium production, which alone uses 3.5% of global electricity and the demand for this metal is currently growing rapidly. In theory, Aluminium recycling requires only 5% of the energy used to produce primary aluminium, although in reality with additional processing for cleaning scrap aluminium prior to melting it, diluting it with primary metal to control quality, and with inevitable downstream processing, a more accurate figure is around 30%. However, as demand for aluminium is growing rapidly, there is currently not enough scrap available to supply current demand, so within Absolute Zero future, primary production must continue - with output reduced in proportion to the supply of non-emitting electricity. Problems of contaminations which undermine the quality of recycled aluminium, could be a basis for innovation in improved processes to separate aluminium in end-of-life waste streams or modify composition in its liquid state.

Critical metals

Critical metals are so called, because of their growing demand and risks associated to their supply. There are no problems of scarcity for these metals, but their global availability is very unequal — most reserves are concentrated in very few locations, often in countries with volatile political environments, and several critical metals are produced as by-products of other larger-volume metals. Most of the production processes for critical metals are already electrified, but these are very energy-intensive due to the need to concentrate these metals from ores in which they naturally have very low concentrations. Unfortunately, recycling critical metals may require even more energy than primary production, because they are typically used as alloys and it is more difficult to separate them from the complex mix of metals in recycling than from the more controlled compositions in which they are found in nature. Absolute Zero, which requires a significant expansion of electrification, is likely to increase demand for critical metals which enhance the performance of motors, but this demand will come at the cost of an unavoidable growth in demand for electric power.

Ceramics

Ceramics and bricks are mostly produced from clays. These need to be vitrified at high temperatures in a kiln. Currently, heat is obtained from fossil fuel or waste combustions, but electric alternatives exist for all temperatures of kiln. Some colours in ceramics require reduction firing, which requires a stage in the kiln with a reducing atmosphere. This is currently obtained by fuel combustion, and thus alternatives to this practice will required. The 60% constraint on available electricity implies a 60% constraint on ceramics production in 2050.

Mining

Mining uses energy for two main purposes: shifting rocks and mined products in heavy "yellow" vehicles, and crushing them to allow the chemical processes of extraction. Both uses can be electrified but at present, yellow vehicles largely run on diesel while the power for crushing and grinding depends on local conditions. Potentially, there may be more energy efficient technologies for crushing and grinding, but already there is a competitive market looking for these, so breakthroughs are unlikely. However, within the constraints of Absolute Zero, the elimination of coal and iron ore mining will significantly reduce the total energy demand of the sector, providing "head-room" in the non-emitting electrical-energy budget for the expansion of mining associated with wide-scale electrification.

Glass

Most current glass production uses natural gas-fired furnaces. These could be electrified, but a reduction in production would be required in proportion with the available supply of emissions-free electricity.

Fertilisers

CO_2 from ammonia production is currently captured and used for urea production. Urea is then used as a fertiliser, delivering nitrogen to the roots of plants and crops, but as urea decomposes in the soil it releases the embedded CO_2 to the atmosphere. Overall, 2 tonnes of CO_2 are produced per tonne of urea used. Ammonium nitrate is an alternative fertiliser to urea, but it is produced from ammonia, thus leading to the same emissions, although all occurring in the chemical plant.

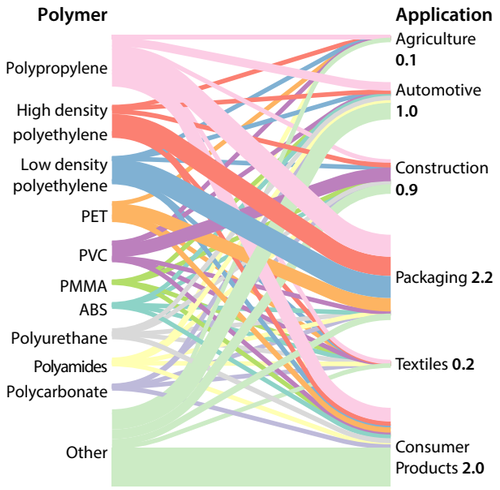
Carbon capture technologies could eventually be deployed, but this would only be compatible with a substantial reduction from current production. However, there are substantial opportunities to reduce energy use by reducing demand for fertilisers. Existing evidence suggests that more fertilisers are used than the nitrogen requirements to grow crops. For example, a study for the Netherlands shows that the use of fertilisers could be halved without loss in productivity, if used more efficiently.

Plastics

Approximately 1 tonne of CO_2 is emitted per tonne of plastic produced, but more than double this CO_2 is produced when plastic waste is incinerated. Plastics are made from oil - and they are therefore the most valuable component of existing waste streams, if the waste is burnt for energy. However, if plastic is combusted, it is in effect a fossil-fuel. As a result, plastic incineration is not compatible with the goal of Absolute Zero.

Plastic can be recycled, rather than incinerated, either by mechanical or chemical means. Mechanical recycling preserves the chemical structure and composition of polymers, and is normal practice within existing manufacturing processes: scrap at the exit of a plastic extrusion machine, for example, can be fed directly back into the machine for re-extrusion. However, this is possible only when the composition is known and under control. The great attraction of plastics is that they can be tailored to every application - with different colours, densities, textures, strengths and other characteristics according to each design specification. However, this tremendous variation is a curse for recycling: in current mechanical recycling of end-of-life plastics, the composition of the resulting product is uncontrolled and therefore of little

Figure 2.16: UK polymer applications (Mt/ year)



value. Furthermore, plastic waste is often mixed with other materials, hence the levels of purity of new plastics cannot be achieved by recycling, which therefore leads inevitably to down-cycling. A frequent example is packaging PET, which cannot be recycled back to food-grade standards and is thus used in lower-value applications.

In contrast, in chemical recycling, polymers are broken down into their constituent monomers which are then recovered to synthesise new plastics. At present, it is only economically attractive to recycle plastics mechanically, requiring less than half of the energy for new production. However, in future, chemical recycling by pyrolysis and gasification may allow plastic waste recovery for high-value applications. As yet, it has proved difficult to operate pyrolysis processes at scale, they require high temperatures, and have yield losses of up to 40%, partly due to use of part of the feedstock to generate heat.

Recyclability is also dependent on the type of polymers available in waste streams. Fig. 2.16 shows the annual flows of plastics in end-use products purchased in the UK by type of polymer and application. Although approximately 40% of annual plastics demand is used in packaging, these have short service lives and are quickly returned to waste streams. A great variety of polymers is used for each application, which hinders the identification and separation of polymers in waste streams, thus limiting the recyclability of plastics. Currently, land-filling plastics leads to almost no emissions. Plastics are stable when landfilled so do not generate methane. However, land-filling neither saves the production of new primary plastics, nor does it contribute to the future availability of material for recycling, unless it is cleaned and separated prior to landfill for storage.

Other chemicals

The chemicals industry produces a wide variety of products. Methanol, olefins and aromatics are produced in much smaller quantities than most plastics and fertilisers, but are important precursors to a variety of chemical products. Emissions arise from energy uses and chemical processes. Although most energy uses can be electrified, it may be very difficult to continue producing many of today's chemicals without releasing process emissions.

Paper

The paper industry globally uses a third of its energy from its own biomass feedstock. Yet, in Europe biomass accounts for half of its total energy requirements, suggesting a global potential for improvement. Absolute Zero emissions would require a conversion of existing fossil fuel-based combined heat and power systems to electrical power processes. Given the constraint on non-emitting electricity availability required by chapter 1, then after complete electrification, paper production would be reduced by approximately 80% of current volumes, to be consistent with UK targets.

Textiles

Most energy uses in the textile industry have already been electrified. However, leather production (which depends on cows) would not be compatible with Absolute Zero for the same reasons given for beef earlier. As washing, drying and ironing account for more than half of the energy uses for most clothing textiles, the industry could promote fabrics that need no ironing and support a reduction in the frequencies of washing and drying.

Engineering composites

Novel nano-materials offer promising properties, which could enable the substitution of some metals across different applications. However, the current total volume of these materials could probably fit into a water bottle. For this reason, it seems unlikely that these materials will have any value in reducing demand for the bulk materials by 2050.

Key Message: Because of the emissions associated with their production, cement and new steel cannot be produced with zero emissions. Steel can be recycled effectively, but we need urgent innovation to find a cement supply. Under the conditions of Absolute Zero, the availability of most other materials will be proportion to the amount of non-emitting electricity available to the sector.

2.3 Resource Efficiency in Construction

Most emissions associated with the construction arise due to the use of materials: the process of erecting buildings and infrastructure requires little energy compared with making the required materials, which are predominantly steel and cement. Under the conditions of Absolute Zero, all steel used in construction will be from recycling - which is largely the case already in the USA, and poses no significant challenge. However, as discussed in the previous section, the industry must learn to make use of considerably less cement. A parsimonious use will make the transition to Absolute Zero possible without putting the material industry under impossible strain. Furthermore, all efficiency gains in one material usually cause reduction in the use of the other, because lower loads always translate to lower structural needs. Fig. 2.17 shows the current uses of cement in the UK as a guide to the search for material efficiencies.

The causes of material *in*efficiency in construction are relatively well understood. The most common is over-specification. The amount of steel in a typical floor of a steel-framed building is about twice what the structural requirements would dictate. This is because the choice of steel beams or steel reinforcement in concrete slabs is not fully optimised and because the decking (the thickness and type of floor slab) is typically oversized.

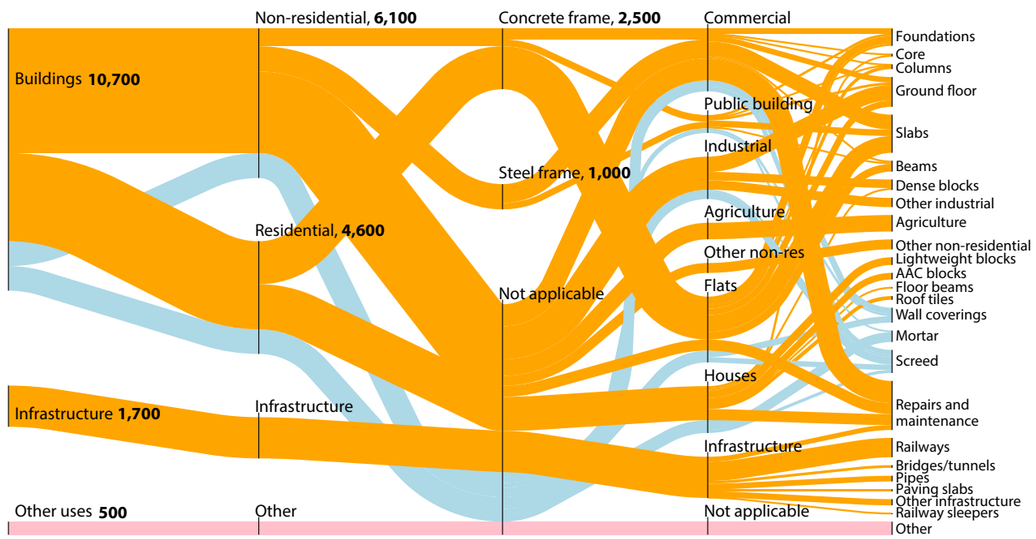
In current UK construction of steel-framed buildings, on average the steel is over-specified by a factor of two, even after accounting for our conservative safety factors. This does not mean that it would be possible to half the amount of steel, be we estimated that it was possible to save at least 15% of the mass of steel with no loss in service or safety. The deckings, are also oversized: the thickness of the concrete layer is larger than required, and the steel plate supporting the concrete in composite construction is frequently double the required thickness.

The building codes currently only specify the minimum amount of material to be used (including the margin of safety). But they could also enforce an upper limit, adding an "and no more" clause. There is also no existing benchmark to compare the embodied energy of the materials in a building per square metre of but this would help drive the efficiency of structural design.

In addition to these sources of over-specification, buildings are often designed for much higher loads than they will ever bear: gravity loading in buildings, predominantly from people, is specified to a far higher level than the physical proximity of groups of people could allow or that ventilation systems could sustain for life in the building. An overestimate of design loading leads directly to material being wasted in buildings. We do not routinely measure loading in buildings, and therefore a research effort is needed. Measuring loading in our buildings, would provide lessons from our existing buildings to transform structural design efficiency.

When specifying the vibration behaviour of buildings, which governs their "feel," engineers usually exceed the requirements of our building codes. However, in use this feel is usually governed by the choice of flooring and the location of partitions, but designers usually ignore those factors, which are not set when the structural frame is

Figure 2.17: Current patterns of cement use in the UK (kT/yr)



chosen. Therefore, a lot of effort goes into making stiff buildings, which require more material and which may be entirely wasted. Better methods of predicting the feel of buildings would help guide design towards more efficient outcomes.

A further driver of inefficiency in our use of materials in construction, independent of over-specification, is the choice of structural form. The choice of the grid (the spacing between columns) is the most important factor in the CO_2 intensity of construction, yet there is little awareness of its importance. The carbon intensity of a building could double if very long spans are specified in preference to shorter ones, even when the users of such buildings frequently install partitions to sub-divide over-large rooms.

Scheming tools, which help guide early design towards a suitable architectural form are being developed. Currently, a designer is faced with a staggering array of options, not obviously different from each other, and will be naturally inclined to choose one with which they have experience. This is probably the cause of the over-design of decking. As the number of options grows – for example with growing enthusiasm for timber construction – the number of options in design will keep expanding, and designers may not be able to realise the promise of new constructions methods New scheming tools to support their decisions can halve the material requirements in construction.

The regularity of structures is also a currently underestimated source of in-efficiency: regular grids can be up to 20% more efficient than more complicated layouts. Novel tools can help structural designer make the right choices early in their projects, and link the choice of architectural form to the best currently available technology, as well as giving a context which may support architects to choose more efficient forms.

Resource efficiency can also be improved by using optimised structural members (slabs, beams, columns). Prismatic structural members in either concrete or steel are highly wasteful, because maximum stress in such members will only occur at one location along the entire length. Modern manufacturing processes can be used to specify appropriate structural shapes (e.g. Fig. 2.18.) Even when designing flat concrete slabs, the pattern of reinforcement is rarely optimised, in part because a complex reinforcement pattern would increase the odds

Figure 2.18: Concrete beam made with fabric formwork

of errors on the construction site. New products such as reinforcement mats which have been tailored for specific site and can be simply unrolled have appeared, but they are not yet fully integrated in the design process of the structural design firms.

Finally using alternative construction material at scale will require considerable changes in design habits. Engineered timber, if it lives up to its promise, will probably take its place besides steel and concrete as a standard frame material. However, engineers are only now being trained to design with timber, and it will take time before it can be used broadly. The trade-off between building tall (probably using high-carbon materials) with low transport requirements, and building low-rise (using low-carbon materials) but with higher transport requirements in a more sprawling approach, needs to be explored.

Steel production, even using a fully recycled route is energy intensive. It would require less energy to re-use beams rather than recycling them by melting. Currently, steel reuse is only a marginal practice, mostly because steel fabrication is an efficient, streamlined process which relies on beams being standardised products. It would be possible to increase the rate of reuse if legislation was adapted to help the recertification of steel beams, but more importantly the construction value chain must develop to accommodate the collection and reconditioning of beams to make them ready for refabrication.

Together, these material efficiency techniques can considerably reduce the need for materials in construction. This is vital to reduce the requirement for cement production to manageable levels. Putting into place all of the material efficiency techniques described here would allow us to keep meeting the needs in Fig. 2.17 with the cement supply implied by the second of Fig. 2.12a and thus to meet the challenge of Absolute Zero.

Key Message: Construction uses half of all steel and all cement, but has developed to use them inefficiently. The requirements for materials in construction could be reduced to achieve Absolute Zero by avoiding over-specification and over-design, by structural optimisation and with reuse.

2.4 Resource efficiency in manufacturing

The manufacturing of basic materials into products and goods is a major source of greenhouse gas emissions. For most products, manufacturing processes themselves cause a relatively small fraction of a product's total embodied emissions, compared to the material input – see Fig 2.19. However, constraints caused by manufacturing practices strongly influence both the material input, and emissions caused by the product during its use. Therefore, under the conditions of Absolute Zero, major changes in manufacturing are needed; driven not just by changes up and downstream of the sector, but also by the need for greater resource efficiency within it.

These changes have some impact on all products, but a critical priority in planning the delivery of Absolute Zero is to focus effort on the sectors with most impact. Having recognised that material production drives most current industrial emissions, Fig. 2.20 allocates the energy use in the first column of Fig. 2.19 to applications to reveal the specific target sectors where material demand reduction is essential. Section 2.2 focused on construction, the single biggest user, and the strategies described there are relevant also to the non-cement components of infrastructure. But the figure clearly prioritises vehicles, industrial equipment and packaging for most attention.

Figure 2.19: Energy use in Manufacturing & Construction

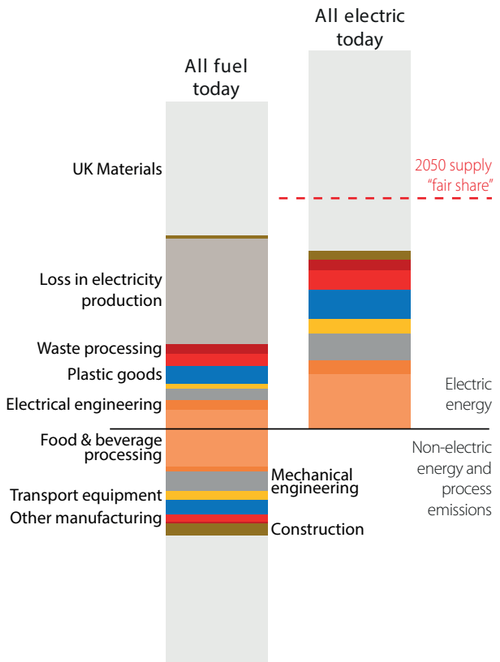
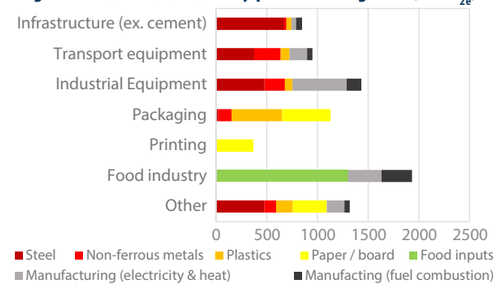


Figure 2.20: Emissions of key product categories ($MtCO_{2e}$)



Responding to changed material availability

In section 2.2 we saw that the availability of materials which today directly emit greenhouse gases in their production will be reduced by 2050. This includes major raw materials such as steel from iron ore and cement, and multiple products of the chemical industry including F-gases, solvents, lubricants, and certain types of plastics. The knock-on effects for manufacturing are huge:

Lubrication is critical for much of manufacturing; from metal forming, to motors, pumps and compressors; but almost all current commercial lubricants are derived from fossil fuels and directly emit greenhouse gases by oxidation either in production or use and so – by a strict definition of Absolute Zero – are ruled out.

Similarly, solvents which emit Volatile Organic Compounds cannot be used. Yet these play a significant role in many industries, including paper coating, degreasing, printing and textiles, but also in coating or painting manufactured goods. Alternatives will be prized and their use widely expanded by 2050. Currently most steel used in manufacturing derives from iron ore; recycled steel is used almost exclusively in construction. New methods will be needed to shape, certify and steel derived from recycled sources. Processes will need greater tolerance to input variation.

Whilst cement and concrete are not widely used in manufactured goods, they are of course ubiquitous in industrial floors, machine foundations and the like: placing a significant constraint on future factories at a time when flexibility and adaptability is key.

Meeting changed product requirements

By 2050 and beyond, the product and composition of many manufacturing industries will be significantly different. For example, Chapter 1 anticipated a 3-fold increase in non-

emitting electricity generation over the next 30 years which means that the need for energy storage will sky-rocket. Section 2.1 predicted major shifts in demand for transport equipment: large uptake in electric vehicles and an end to plane or ship building. Similarly, widespread electrification of domestic and industrial heating will require a massive increase associated equipment such as heat pumps. A shift to vegetarian diets would change the food industry significantly. Increased consumption of processed meat substitutes with lower emissions embodied in the food inputs, would require new processing capability and could need more energy in processing.

The scale of material and resource input to enable these changes is significant; looking at wind electricity generation alone, increasing capacity at the rate predicted creates the opportunity for a substantial increase UK industrial output. On the other hand, Section 2.1 anticipates that by 2050 consumers will require products that last longer and can be used more intensively. This will present manufacturers with the challenge of producing higher quality, higher value products. These may be individually more materially intensive but, with a reduction in total volume of sales, manufacturers will see a reduction in their total throughput.

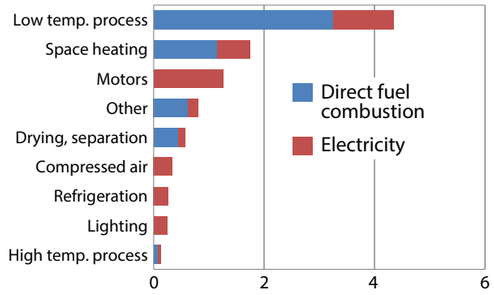
Improving resource efficiency

In a world with much-reduced primary energy availability manufacturers will need to make a step change in resource efficiency; both in material and energy input.

Material efficiency

Various material efficiency measures are technically possible in the manufacturing of goods, components and equipment, including the reduction of process scrap, optimised component design and re-use or re-purposing of components. Large emission savings are possible by reducing process scrap. In machining up to 90% of material can be wasted. For example, machining of aerospace fan blades from solid titanium can produce 90% waste in the form of machining chips. The paper industry produces pulp

Figure 2.21: Annual energy use (MToe) of key processes



residue as waste containing high cellulose fibre and high calcium oxide, both of which can be used in fired clay brick production. Other uses are for land-filling, incineration, use in cement plants and brickworks, agricultural use and compost, anaerobic treatment and recycling.

The automotive industry in the UK generated 0.5% of the total commercial and industrial waste in the UK, at 1.85 million tonnes, 41% of which is metallic, 28% is mixed ordinary waste, 8% chemical and medical waste, and the remainder mineral, paper, wood and plastic. Many nascent technologies have been proposed that could reduce process scrap such as additive manufacturing, precision casting or forging and so on. However, the significant variation in performance between companies illustrated in Fig. 2.22 suggests that the problem is just as much in the management of component and manufacturing design processes.

Shape optimisation of components could further reduce the material requirements of manufacturing. Whereas a given component - whether it is food or beverage can, drive shaft, or a structural beam – would often ideally have variable thickness along its length, or a hollow interior, current manufacturing process are not set up to produce such features. Material savings could be achieved by the development of new manufacturing processes: the economies of scale promote production of components with uniform cross-sections, but optimising material use would require a distribution, and new computer-controlled

Figure 2.22: Material utilisation rates for selected cars

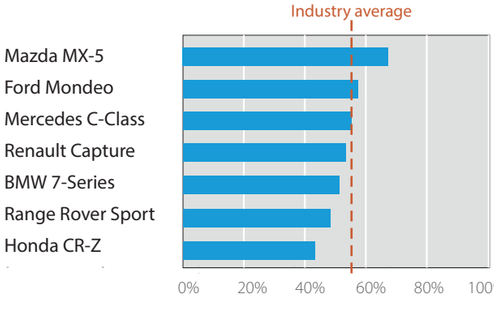
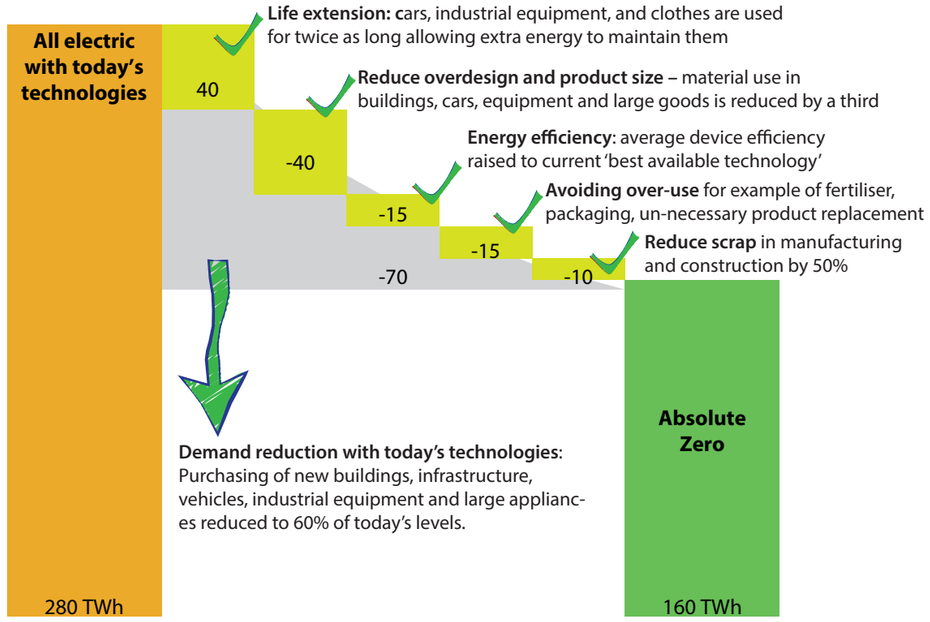


Figure 2.23: Reducing energy use in manufacturing and construction with incremental technologies or reducing demand



equipment can facilitate this change. Functional grading – generating different mechanical properties in different parts of the component - or using higher strength or lighter materials can also contribute.

Changes of the nature described have all been demonstrated at differing technical 'readiness' but their deployment requires large disruptive changes in management practices, skills and manufacturing processes.

Energy efficiency

Direct energy use in manufacturing will need to reduce if electricity supply is restricted to zero-carbon sources by 2050. Some of this reduction could be achieved by energy efficiency. In the UK, the use of energy in downstream industries is dominated by low temperature process heating, space heating and motors, with a long tail of other uses as shown in Fig 2.21. Recent estimates suggest that it may be possible to quarter electricity consumption over the next 10-15 years with the appropriate deployment of conventional technology such as motor drives, pump and compressed air efficiency measures, and the use of heat pumps.

Product standards

Many positive changes are already occurring and many others are both technically feasible and cost-saving in the long run. To deliver the rapid pace of improvement needed we propose that stretching, and imaginative embodied emissions standards are phased in for almost all manufactured product and imposed equally on UK manufacturers and imported goods. Such standards are already widely familiar within manufacturing, whether for safety, inter-operability or use-phase energy efficiency. These must now be extended to embodied emissions and – as matter of urgency - be attached to the major programmes of industrial product development delivering the widespread changes in energy, transport equipment, food infrastructure. If these are imposed fairly on traded goods, it would create a great incentive for UK manufacturers to develop and benefit from the novel products and processes compatible with Absolute Zero.

Fig. 2.23 summarises the analysis of this and the previous section: the energy required to power UK manufacturing and construction, once electrified, can be reduced by a combination of changes to product specification and design, product longevity and process efficiency.

Key Message: Driven by inventive new embodied emissions standards, manufacturing will adapt to three major changes: 1) reduced availability of current inputs, 2) radically different product composition and requirements, and 3) the existential need for improved resource efficiency.

2.5 Breakthrough Technologies

The purpose of this report is to focus attention on how we can really deliver zero emissions by 2050, using today's technologies and incremental changes in use. This is because breakthrough technologies take a long time to deploy - as shown in the box story on page 10 - and we don't have enough time left. However, beyond 2050, new technologies will emerge to transform the energy and industrial landscape, and some of them will be those under development today.

The options surveyed on this page are therefore post-mitigation technologies: after we have met Absolute Zero through complete electrification, a 40% cut in energy demand and the elimination of emitting activities without substitutes, these technologies may later grow to be significant.

Generation

Of the non-emitting technologies in current use, hydro-electricity is difficult to expand, due to geography, and as discussed earlier, the use of biomass for food will exclude its use at scale for energy generation. However, nuclear power could expand. Following the Fukushima disaster in 2011, Japan closed its nuclear reactors and Germany decided to move permanently away from them. However, France continues to generate much of its power from nuclear power, and in the UK, Hinckley Point C is under construction although this is a big, costly project with uncertain completion date. New "small" modular reactors are also under discussion. At present, none are operating world-wide, with two under construction, but potentially beyond 2050, these could make a significant addition to generation. More remotely, nuclear fusion which has been under development since the 1940's is still decades away from generating any energy even at laboratory scale, so cannot be included in planning.

Beyond wind and solar power, the other renewable generation technologies under development are geothermal, tidal and wave power. Geothermal generation which operates at scale in Iceland, New Zealand and Costa Rica is unlikely to be significant in the UK and is operated only at very small scale. Two large tidal power stations operate world-wide, in France and Korea, at a scale of about a quarter of a gigawatt, but although the Severn Estuary has been explored as an attractive site, the UK has no current plans for a first installation. World-wide there is no significant generation based on wave-power. As a result, while these are important areas for development, it is not possible to anticipate any significant new generation from these new renewable technologies.

Energy storage and transfer

Wind and solar power are intermittent, so create a challenge of matching the availability of electricity supply to demand for its use. This can be addressed by storage (for example by batteries or the pumped hydro-station at Dinorwig) or by controlling demand to match availability, for example by allowing network operators to decide when domestic appliances and industrial processes can operate. There are already many developments in this area in the UK, and we assume that they can operate at sufficient scale in 2050 to prevent the need for excess generation.

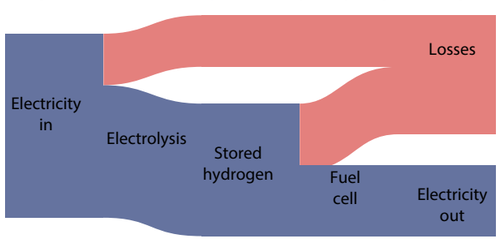
Batteries can operate at large scale, but remain heavy. For static applications this is not a problem but for transport it is constraining: the battery accounts for around one quarter of the weight of a two-tonne Tesla Model S. Technology developers have therefore looked for alternative forms of energy storage to use in transport, and found two important options: hydrogen and ammonia.

Hydrogen is currently produced mainly (95%) from fossil fuels by steam reforming methane, which leads to the release of a significant quantity of greenhouse gases offering no benefit as a form of energy storage. However, it can also be made from water by electrolysis, although as Fig. 2.24 shows, this involves losses which depend on the application, but may be higher than those in the figure depending on the form of storage used. If, in future, we have an excess supply of electricity from non-emitting sources, we could use it to make hydrogen, which could then be used to power vehicles.

Ammonia combustion for shipping may be available in the future, but it currently leads to the production of NOx, which is a powerful air pollutant. Additionally, ammonia is currently produced from fossil fuels, which results in emissions. Although it is possible to use fuel cells to produce ammonia using renewable electricity, there is currently no such process in commercial operation, and its implementation at scale would again be an additional burden to the decarbonisation of the power grid.

One further opportunity for energy storage and transfer is through heat networks which capture "waste heat" from industrial processes and use it, for example, for domestic heating. Around 1% of the UK's homes are heated by heat networks, but expanding this number has proved difficult due to the high cost of the required infrastructure.

Figure 2.24: "Round-trip" efficiency of hydrogen storage



Emissions capture

Although not all related to the energy system, several novel approaches have been proposed to capture carbon emissions. Carbon Capture and Storage (CCS) is used to a very small extent by the oil industry to increase production through the process called "Enhanced Oil Recovery": compressed CO_2 is pumped into the rocks in which oil is stored to drive more of it to the well.

For over twenty years CCS has been proposed as the key technology to allow continued generation of electricity from gas and coal. However, the only power plant operating with CCS – the Boundary Dam project at Saskatchewan in Canada, a very small 0.1GW power station – does not produce transparent figures on performance, and when last reported on by researchers at MIT, was capturing but then releasing its emissions. This technology, despite the very well-funded lobby supported by the incumbent oil and gas industry, is far from mature or ready to be included in meaningful mitigation plans.

Plans for "Bio-energy CCS" or "BECCS" claim to be carbon negative – burning biomass and storing carbon permanently underground – are entirely implausible, due to the shortage of biomass, and should not be considered seriously.

Carbon Capture and Utilisation (CCU) has become a key technology promoted by the industrial operators of conventional plant, particularly the steel and cement industry, but it requires significant additional electrical input, which clearly will not be available before 2050. In future CCU allow conventional steel and cement production to re-start, but only when we have excess non-emitting electricity.

In fact, the idea of carbon capture and storage requires no new technology, as it could be developed by increasing the area of land committed to forestry or "afforestation". We aren't short of tree-seeds, and instead the world is experiencing deforestation under the pressure of needing land for agriculture to provide food. Planting new trees is the most important technology on this page, and does not require any technological innovation.

Industrial processes

In addition to its potential application in energy storage, hydrogen creates a further opportunity in industrial processes because it is sufficiently reactive that it could be used to reduce iron ore to pig iron without releasing carbon emissions in the reaction. Steel has been produced at laboratory scale by hydrogen, and pilot plants are now being developed to demonstrate higher scale production. However, it will only be consistent with a zero-emissions future when the hydrogen is produced with non-emitting electricity, and we have no spare non-emitting electricity to allow this to happen.

Beyond 2050, the incumbent operators of blast furnace steel making, have several process concepts for making new steel from iron ore without emissions. The three main areas being discussed are: separating CO_2 from other blast furnace gases, and applying CCS to it; using hydrogen instead of coke to convert iron ore to steel; separating CO_2 from other blast furnace gases, and using it for other purposes via CCU. All three routes show rich technological opportunities, but will not be operating at scale before 2050.

Flight and shipping

Electric planes are under development, but difficult: the limited rate of improvement in solar cell efficiency shown in Fig. 1.10 suggests that solar power will be never be sufficient for multi-passenger commercial flight. Meanwhile, we have yet to find a sufficient breakthrough in battery development to anticipate sufficient light-weight storage. The most promising route appears to be synthetic jet-fuel - which, inevitably, will be important only after a substantial increase in non-emitting electricity generation.

The decarbonisation of shipping is difficult with current technologies. Although short-distance shipping can be electrified using battery-powered engines, long-distance shipping requires a combustion process. Nuclear propulsion of ships offers a viable alternative to current long-distance shipping and it is already used, although almost only in military vessels. Some commercial operators are currently exploring the opportunity to add sails to conventional ships to reduce their diesel requirements.

Key Message: The problem with breakthrough technologies is not our shortage of ideas, but the very long time required to take a laboratory-scale idea through the technical and commercial development cycle before it can begin to capture a substantial share of the world market.

3. Transitions:

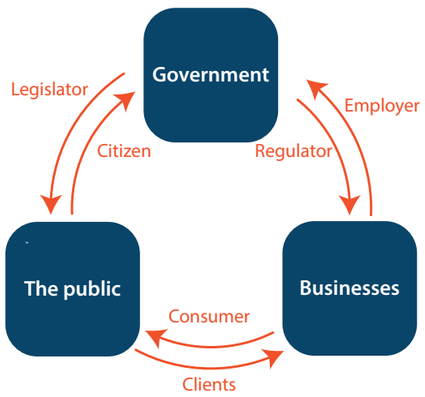
Key Message: No one actor can bring about Absolute Zero. Delivering it is a journey depending on co-operative action by individuals, businesses and governments acting on good information

Absolute Zero is a journey

Action on climate change depends on the co-operation of three "players" illustrated in Fig. 3.1. The public, the government and businesses must act jointly to transform the way we produce, consume and live. Large sections of the public are increasingly concerned with climate change, and some take individual actions such as eating less meat, looking for locally sourced products or taking the plane less often. Politically, this has translated to a growth in the support for Green parties across Europe. Businesses, driven by the demands of the public and driven to efficiency are seeking more efficient production methods and developing products consistent with a zero-emissions future. Governments embrace the drives of the public and businesses to grow the economy and gain votes.

Despite this goodwill towards change, the important transformations outlined in this report do not seem to be happening, or at least not at a sufficient pace. A key reason for this is that these transformations are attempted without the required trust building between the actors which can make them successful. The actors of change are in effect locked in a prisoners' dilemma, and the changes proposed make it seem like a static version of the game. The prisoner's dilemma is a theoretical game where the best outcome for the players cannot be achieved if the players only follow their own best interests. There are many variants to the story but in substance it runs like this: two bandits just successfully robbed a bank and were caught soon after for some minor offence. They are kept in separate cells, and each is told their accomplice has also been caught. They can defect and accuse their accomplice of the robbery, in which case they'll get at least a reduced sentence, or they can cooperate and refuse to accuse each other. Should they both defect, they'll both have a reduced sentence. Should they both cooperate, they'll both have a small fine, should one cooperate and the other defect, the defector will go out free and the cooperator will get a full sentence.

Figure 3.1: The three "players" of climate mitigation



Game theory predicts they should both defect: indeed, there is no outcome from cooperating which cannot be improved by defecting… Every day, all of us are faced with many such dilemmas – but every day we cooperate rather than defect! This is because the prisoner's dilemma when played over and over is a completely different game which is won by achieving cooperation. When considering the so-called iterated prisoner's dilemma, it's not single moves but strategies which matter. This is a well-studied problem, and the winning strategies which achieve cooperation share a number of basic characteristics: they punish defectors, they reward cooperators, they are simple enough that they can be understood by observers. Other research looking at how humans play in games compared to the predictions of game theory suggests another crucial quality of winning strategies: the cooperative strategies must also be fair. Marginally cooperative moves will be treated as defections.

Similarly, the transformation required for climate change mitigation needs to be played out like the repeated game, and not seen as a single huge step which will most likely be resisted and fail. Fortunately, three-player games favour cooperation somewhat, unlike the two-player variant. Unfortunately, having more players may drive each one individually to try and delay making changes. To achieve the scale of transformation required, small incremental changes are the immediately necessary steps to build and reinforce trust between the actors.

Case study: reusing steel

Currently, most of the steel from demolitions is recycled. There is nothing else which can be done with the reinforcing steel of concrete, but steel beams having standard sections and not being damaged from their service as structural elements could be reused. If not directly, after some sand-blasting and the fitting of new connexions the beams are as good as new. Most of the research on the barriers to steel reuse focuses on the certification problem: steel to be used in construction needs to be certified, but the process of obtaining certification assumes the beam is coming out of a mill and is not transposable to already used beams. However, is is possible for a small price premium to test the beams and guarantee that they have all the appropriate properties.

What we found is that the key obstacle in the supply chain was that steel re-use puts the buyer of the building wanting to use steel from reuse and the fabricator responsible for the conditioning of beams in a prisoner's dilemma. Reconditioning the steel takes approximately twice the amount of time to condition a new steel beam direct from the foundry. Although the fabricator can charge for this time, a project being abandoned – always a risk in construction – will translate to large losses. Therefore, all projects that we could study where the fabricator was not part of the planning, failed. Our proposed solution is for steel stockist to take on the job of reconditioning and recertifying steel so that the fabricators need never know whether the steel is from reuse or not. Acting as a trusted intermediary, this would avoid the project failures due to fabricators not wanting to shoulder all the risk. The upfront investment could be helped by government grants, and we showed that this would be overall profitable.

Case study: Cycling in the Netherlands

After the second world war, the Netherlands had, like the rest of Europe embraced cars as a symbol of freedom and mobility and had built highways and roads to accommodate this new transport mode. In 1971 alone, 300 children died in the Netherlands from accidents involving cars, leading to widespread protests. In 1973-74 the oil crisis caused oil shortages, leading the Dutch government to look for strategies which would lower the oil dependency. The protesters were demanding a return to the biking culture which had been an important part of Dutch habits until the war, and the government took this occasion to launch a number of bike-friendly initiatives: a number of car-less Sundays in the years. Some city centres were made car-free. These moves proved popular and were followed by the construction of bike-specific infrastructure.

From the mid-70s onwards, bikes were integrated in urban planning decisions, meaning not only cycles paths being built, but traffic-calmed streets would be favoured, and bike parking be available at convenient locations, and bike traffic be integrated in the general public transport infrastructure. As the bicycle is seen as a symbol of the Netherlands, it was possible to pass more stringent legislation: for example since 1992, in an accident, it is always the motorist's insurance which is liable for the costs in the Netherlands. Safe interaction with bikes is part of passing one's driving license. As the popularity of bikes grow in the 90s and 2000, larger investments in bike infrastructure became possible with the support of the public, leading to even more bikes being ridden.

Overall, the current Dutch biking culture is the result of a long process where multiple changes to legislation, habits and infrastructure were self-reinforcing, leading to today's situation where the Netherlands is Europe's leader in kilometres cycled.

3.1 Individuals – at home and at work

Protesters and school strikers have increased our awareness of the need to address climate change. An individual wanting to reduce their personal emissions can find a wealth of information on social media, websites and podcasts detailing actions they could take. Behavioural changes required to deliver zero emissions by 2050 are already being practised by some people in some places: some people already choose not to fly, to be vegan, to car share, to lower the temperatures in their homes and offices. If large scale social amplification could occur, as it did with the 'Me Too' movement, surely a cultural change could occur to enable zero emissions by 2050?

Although public awareness of the need to act has increased, the UK has not meaningfully reduced its resource use in recent decades, with the International Energy Agency reporting total final energy consumption has reduced by only 7% since 1990 levels. Individuals continue to use nearly as much energy as they did 30 years ago, suggesting that existing strategies to motivate individuals to use less energy are not generating the scale of impact required.

Social norms and individual behaviours

There is a misalignment between the scale of actions recommended by government (e.g. energy conservation) and those most commonly performed by individuals (e.g. recycling) . Actions which can have a big effect, such as better insulation in houses and not flying, are being ignored in favour of small, high profile actions, such as not using plastic straws. This is enabling individuals to feel satisfied that they are 'doing their bit' without actually making the lifestyle changes required to meet the zero emissions target. If large scale social change is to be successful a new approach is needed.

Whilst the thought of society taking radical, meaningful steps to meet zero emission targets could be criticised for being idealistic, we can learn from historical cultural changes. Not long ago, smoking cigarettes was encouraged and considered to be acceptable in public spaces that children frequented, drink-driving was practiced with such regularity that it killed 1000 people per year in the UK, and discrimination based on sexual orientation was written into law. These behaviours now seem reprehensible, showing society is capable acknowledging the negative consequences of certain behaviours and socially outlawing their practice. Focus should therefore be centred on expediting the evolution of new social norms with confidence that change can happen.

Evidence from behavioural science, and the long experience in public health of changing behaviours around smoking and alcohol, shows that information alone is not enough to change behaviour. To make the types of changes described in this report, we will have to think more broadly on the economic and physical contexts in which designers, engineers and members of the public make decisions that determine carbon emissions. At the same time, clear, accurate and transparent information on problems and the efficacy of proposed solutions is essential for maintaining public support for policy interventions.

The phrasing of communication is also important. Messages framed about fear and climate crisis have been found to be ineffective at motivating change. The longevity of the challenge of reducing emissions, and the lack of immediate or even apparent consequences of small individual actions mean it is challenging to link to them to the large-scale climate crisis. This allows individuals to make decisions which contrast with their desire to reduce emissions. Scientific description is not always the most effective means of communication, and language used to promote zero emissions should no longer focus on an 'eco-friendly' and 'green' lexicon, but rather candid descriptions of actions that appeal to human fulfilment. Evidence from time-use studies shows that human fulfilment does not strictly depend on using energy – the activities we enjoy the most are the ones with the lowest energy requirements. Consumers can be satisfied in a zero emissions landscape.

Individuals and industry

If net-zero targets are to be met, all of society needs to change, not just those motivated by the environment. Therefore, as well as persuading and supporting individuals to change with environmental campaigning and one-off sustainability projects, industry should embed a net-zero emissions strategy into business-as-usual, only offering products and services which meet their consumers' welfare needs without emissions.

This change will be driven by individuals acting in their professional capacity, as managers, designers, engineers, cost consultants, and so on. A structural engineer designing a concrete-framed building has vastly more influence over carbon emissions through their design decisions at work than through their personal lifestyle. Therefore, as well as the transitions in businesses discussed in the following section, this section applies also to individuals at work.

Key Message: Changes to social norms and individual behaviours can be positively framed to appeal to human fulfilment. Motivated individuals can be as effective at work as at home.

3.2 Transitions in businesses

Many of the opportunities and changes identified in the first sections of this report will involve businesses making changes to the types of technologies they use, or the way they use them. But this type of change can be difficult to motivate. This section examines why this is, and discusses the role of incentives, market pull, standardisation and collaboration in achieving the change required.

Challenges in changing technologies for zero emissions

We are surrounded by a constant stream of innovation in technology in some areas, such as smartphones – so why is it that some other industries have been slow to respond and to integrate relevant innovations into their operating models? In general, the reason is that new production technologies are introduced at the same as a new generation of products is launched. The new manufacturing technologies and processes are often not central to the functionality of the next product but are driven instead by improvements in cost, quality and logistics. So in areas without a rapid cycle of introducing new generations of products, it can take a long time for manufacturing innovations to be adopted.

In such cases, thorough assessment of technology merits, maturity and readiness are carried out, especially where change represents some form of risk. Without the driver of a new product launch, and associated new revenue stream, firms have displayed a risk-averse attitude towards making significant transformations in the production technologies they use. This is particularly true for safety-critical applications. In such cases, novel technologies have had to pass the test of time before being considered for full deployment. Another reason behind gradual technology adoption is the lack of propensity to invest, especially in highly established industries where the cost of new capital would be prohibitive.

Incentives for technology innovation

Using the "carrot and stick" analogy, it is easy to understand that innovation can have a difficult time permeating into an organisation without the right type of leverage and motivation. Governments can impose additional taxes, policies and regulations to achieve the desired changes but this could be short lived with the next batch of policy changes. Emissions and energy caps can be seen as a "stick" but financial rewards and customer-valued green credentials will be perceived as a "carrot".

Ideally there should be a market pull that is driven by the end customer. Organisations are more likely to adopt innovation and technology when there is a direct correlation to increased revenue and returns. They are also more likely to pursue targets that result in products and services that use less resources but still valued equally or greater by the customer. Consumers are more aware of the macro effects of their purchasing choices and there is a move towards companies that have the same brand values. However, for a business, it can be hard to benefit from this, as the relevant qualities are not easily visible to the end customer. For example, you cannot tell just by looking at a washing machine whether it was produced from renewably-powered recycled steel, or carbon-intensive steel from a blast furnace.

The achievement of Absolute Zero almost certainly requires life extension and better utilisation of certain categories of product, but with progressive insertion of more sustainable manufacturing and through-life engineering technologies throughout life in service. This creates a conflict: life extension and better utilisation of existing products implies that new products need to be introduced less frequently – but as described above, generally more sustainable production processes are difficult to introduce in the absence of new generations of products being developed. A new mechanism is therefore needed to drive forwards the adoption of positive technological changes. The most obvious means of doing this via public intervention would be the establishment, of some form of 'roadmap' which sets out progress.

The role of standardisation

Standardisation can play a significant role in reducing industrial and domestic energy use and CO_2 production. In many industries, standardisation and sharing best practice have paved the way to less resource duplication and greater customer experience. An example that is often mentioned is the light bulb but a more modern example would be the phone charger. In the early days of the mobile phone industry, not only did every manufacturer have their own chargers but every model had its own connector type. Once customer habits were analysed, it was found that customers wanted to upgrade to a new phone every few years, therefore very quickly there would be a build-up of useless chargers and connectors ending up in landfills. Several of the major manufactures developed a standard charger and connector that would be used for all models going forward. This had 4 main benefits:

- Reduction in unnecessary charger variation and legacy part production.
- Increased customer experience as phones could be charged with any charger and no longer limited to one connector.

- Phone manufacturers diverting funds and resources away from charger and connector design into other parts of the product that were more valued by the customer.

- Users investing in higher quality chargers that could be used for years without needing replacement and a reduction in E-waste.

In other industries current practice often requires specialised components and parts that are designed specifically for their intended use. With standardisation comes the reduction in design flexibility. In an already saturated market place, businesses are trying to differentiate their products and services form one another. Customisation currently allows them to achieve these goals, but as discussed above, the future environmental benefits of standardisation could provide an alternative source of differentiation.

It is possible that the progressive roll-out of standards over time could form a central and tangible element of any roadmap for achieving Absolute Zero. The development of standards which drive positive change would however be entirely reliant on some key principals of backward compatibility, such that the implementation of each new standard avoids immediate obsolescence of existing assets.

Making collaboration work

The achievement of Absolute Zero seems to be beyond the ability of individual firms, and even nations, to enact. It requires a level of cooperation which has perhaps only been seen during times of war.

Moving beyond the purely competition-based model and integrating some learning from the collaboration model can be beneficial to competitors as well as the environment. As well as eliminating obvious duplication of resources, a new level of cooperation would be needed so that the benefits of shared learning can rapidly permeate through supply chains, and horizontally across sectors. This presents a more complex legal and organisational challenge to the traditional manufacturing and business model, but one which could create new opportunities for early adopters.

The necessary transition will incorporate the current move beyond the traditional manufacturing line to more flexible manufacturing for increased agility while taking a balanced and holistic planning approach to enable through life considerations to be made. The role of analysis in this model based on increased computing power, but also the carbon impact of data storage and transfer is a complex one. Gathering information on the whole manufacturing process from all participants in the supply chain and then analysing the results to produce the holistic resource usage is one of the ways to truly understand what goes into the final product. Insights from this information will allow for the development of a valid roadmap to Absolute Zero, but there are challenges to obtaining and using this information that will be discussed later, in section 3.4.

A look to the future

Technology innovation and change readiness is becoming a desirable quality. With shortening product life cycles, organisations need to adopt a more agile approach to respond to market needs. Catering to this consumer mentality has led to the production of lower quality products that fail in the time the consumer would be looking to upgrade or replace the product. An extension of through-life engineering approaches beyond ultra-high capital value assets into more mainstream consumer products is needed. Essentially this means producing much higher quality products with parts that can be dismantled, retrieved and reused. Products could either be disassembled and reassembled with some modifications and resold, or they could be cascaded down into a completely new product. This would require forward planning, standardisation and modular design thinking.

Organisational and inter-organisational culture will need to match the aspiration of Absolute Zero over time to become, itself the great incentive and driver of a positive cadence of change. No organisation can outrun their legacy, therefore a roadmap that commits them to real change while keeping the business profitable now and in the future is desirable.

This section has focused on technology transitions in existing businesses, but successful disruptive transformations often come from outsiders and new players. Therefore, support mechanisms also need to exist for new businesses bringing zero-carbon-compatible business models and production processes as an alternative to the status quo.

Key Message: Agreed roadmaps, new forms of market pull and collaboration are needed to spread the required technological innovation through industry.

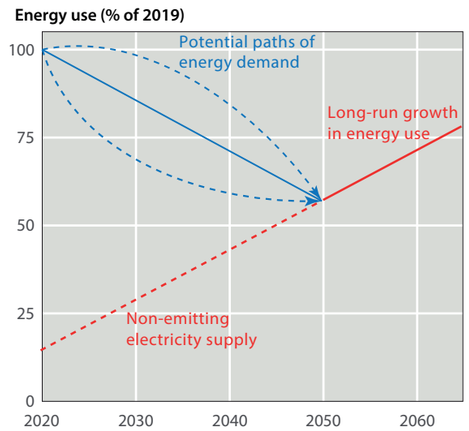
3.3 Action by Government

The government will need to act to create the context in which the individual and supply-chain changes described in the previous sections can develop. There is also a strategic choice about the speed of transition which should be pursued.

Fig. 3.2 shows three potential paths for energy reduction to reach Absolute Zero in 2050. This is predicated on growth in the supply of energy from renewables growing at the rate indicated in Fig. 1.1. This means that demand has to reduce to 60% of its current level by 2050. Growth in energy use beyond 2050 will be driven by ongoing renewable and other carbon-free technologies. The distinction between the pre-2050 and post-2050 analysis is that the steps taken to meet the 2050 target must rely on technologies which are already in existence, and have the clear mechanisms to be scaled, whereas post-2050 growth can reflect new technologies. The three potential paths for energy reduction reflect three different approaches, depending on the extent of delay. What these three paths do not show is that the cost or sacrifice needed for an extra percentage point reduction is not constant: initial reductions are likely to be much easier. This in turn implies that if the desire is to spread the cost of reduction equally over the 30 years to Absolute Zero, then the actual path needs to reflect a sharp early decline, as in the lower dashed blue line.

Absolute Zero means two things: first, that no carbon can be produced by any industry or household; second, averaged across the economy, energy consumption must fall to 30% of its current level. This distinction between the carbon reduction, which is an obligation on all industries, and an energy reduction which is on the average, leads to very different substitution possibilities: there are no substitutes for the reduction of carbon to zero, but there needs to be a mechanism for allocating scarce energy resources. Ensuring carbon is at zero is a regulation issue, with prohibitions on the use of carbon similar to prohibitions on the use of asbestos. Ensuring energy is cut in the aggregate requires an allocation mechanism, and the price of energy to reflect its scarcity. In such a scenario, the owners of the means of production of renewable energy will make very large profits. This in turn raises both efficiency and distributional issues.

Figure 3.2: Pathways of restraint and growth



We break the discussion into four components: first, on the possibilities for substitution away from carbon and energy use across different sectors; second, on the impact on the types of job and the location of jobs; third, on the overall impact on output; and finally, on the implementation.

Production Substitution

At the heart of understanding the impact on the economy of Absolute Zero is an understanding of the substitution possibilities away from carbon and energy in different industries and production processes.

Section 2.3 discusses the options for the construction sector: the production of cement involves the emission of carbon and so cement in its current form cannot be used in construction. At present there is no alternative to the use of cement and so the construction industry has to radically change its production process or close. In this case, radically change means either reverting to using wood or other natural products, or successfully developing the alternatives to current cement production described in Section 2.2. These options, however, limit the size of buildings and so the sector cannot continue as it is. This has implications for the way in which businesses and households operate. Buildings need to be reused rather than rebuilt. On the other hand, it is not clear how the existing stock of buildings will be maintained, and the conclusion is that building space (residential and commercial) will have an ever increasing premium

The difficulty of the construction industry highlights the impact on any assets being used in an industry where there are no substitutes for carbon – such as planes, or industrial plants. The value of these assets will be zero in 2050 and this should directly affect the desire to invest in those assets now. This points to the implementation issue: realising the value will be zero in 2050 may encourage greater use in the run up to 2050 – for example, putting up new buildings at a much faster rate for the next 30 years, knowing that construction must then halt. On the other hand, Fig. 1.1 makes clear that the value of investment in processes of carbon-neutral energy production will increase sharply.

Jobs and Location

There are two key implications for how we live our lives: first, buildings will become much more expensive because the restrictions on building which generate substantial scarcities; second, transport will become much more expensive because the limits on air travel will generate excess demand for other forms of transport. By expensive, we mean the direct costs to an individual or firm, but also indirect costs in terms of reduced quality. We would expect these two substantial changes to lead to pressure on the amount of space any one individual uses, and also where people choose to live and work. This points to increased centralisation, with growth in cities.

The wider problem with the changes in labour is knowing what type of labour or jobs will be in demand. Those who are starting secondary school now, in 2019/2020, will be 43 in 2050. Thinking about what education is appropriate for a very different set of industries is a key question. Should we still be training airplane pilots? Or aeronautical engineers? How are we training architects, civil engineers? Education decisions are far more persistent than capital investments. This in turn highlights the needs to take decisions on investments now where the lead times are very long or depreciation rates very low.

Overall Impact on Output

Economic growth in the industrialised world has been associated with increasing energy use. Long-term growth rates will also be constrained by the rate at which energy production can grow which depends on the growth rate of renewables. The key question in the transition is how much will output decline to reach a level where only 30% of current energy is being used and no carbon is being produced. We have discussed the direct impact of this on the construction and transport sectors. What this misses is the inter-dependence of the non-emitting and emitting sectors. Specialisation in production and the substitution of energy for labour have been key drivers for growth and increased productivity. The open question is whether specialisation can still be achieved without the reliance on energy.

These impacts on output will not be felt equally across the country. Industries are typically geographically concentrated – such as steel production – and this means that large shifts in production will have concentrated impacts. Rural or more isolated communities are likely to be disproportionately affected. The largest distributional impact, however, is intergenerational: the cost of hitting Absolute Zero will be borne by the current generation.

Implementation

The changes in behaviour to achieve Absolute Zero are clearly substantial. In principle, these changes could be induced through changing prices and thus providing clear incentives for behaviour to change. The alternative is that the government prohibits certain types of behaviour and regulates on production processes. Given the difficulty for the government of knowing what production process to change or what options for innovation are available to companies, the natural decentralised solution is for the government to either put a price on carbon or to restrict its use directly. The push for Absolute Zero means the distinction between these two approaches is irrelevant: the price of carbon must be prohibitively large by 2050 to stop all demand. In the run-up to 2050, the question is how fast must the price of carbon be increased, or equivalently, how fast must restrictions on the use of carbon be put in place. It is understanding this time-line for the price increase (or time-line for the strictness of restrictions on use) which is the key issue for the implementation.

The underlying point is that any asset which uses carbon will have essentially zero value in 2050. This in turn may encourage greater use in the run up to 2050. This sort of response is clearly counter-productive: the climate problem is about the stock of carbon, rather than the flow.

A natural question in considering implementation of the 2050 is how to evaluate the cost to the economy of various measures. For example, how to compare the cost of installing solar panels to the cost of driving smaller cars. Individuals' willingness to pay gives a measure of the value of installing solar panels (rather than take electricity from the grid) or the value of driving a small car (rather than a larger one with the same functionality).

Key Message: The effective price of carbon must be prohibitively large by 2050. A key issue for how to implement this is the timeline for how the price must grow (or restrictions must become more strict) from now to 2050.

3.4 Information

Information has a critical role to play in guiding transition to Absolute Zero emissions. Data about our present situation is needed to prioritise change and innovation, to monitor progress, and to identify 'bright spots' of good practice. We also need to understand how the future might develop and how we can make choices now that are robust to future uncertainty. However, information alone is not sufficient to cause actual changes in behaviour, and we should be aware of lessons from behavioural science to maximise the effectiveness of information.

Information on the present

Understanding the current scale of our different activities that drive emissions is key to prioritising the behaviour changes and technical innovations that would most effectively lead to emissions reductions at the scale required. Put simply, the impact of a change (whether behavioural or technical) can be represented as:

$$\text{Impact of change} = \text{Scale} \times \text{Change in flow} \times \text{Impact of flow}$$

For example, in construction it is possible to use post-tensioned floor slabs in place of the standard slab types, to achieve a 20% reduction in cement use (the 'change in flow' of cement entering construction). However, this technique is only applicable to a fraction of all the floor slabs that are constructed (the 'scale'), and the overall impact depends on the impact factor of the flow (in this case, GHG emissions per tonne of cement). Clearly, the overall impact of a change depends on all of these factors. An understanding of all three is critical to formulating a roadmap for change (Section 3.2) that can really reach Absolute Zero emissions. The same applies to research agendas, where there has been more research and policy interest in reducing food waste than on reducing meat consumption, despite the former contributing an estimated 1–2% to emissions and the latter an estimated 50% . Data on how things are currently happening can also support change through identifying 'bright spots' where good practice is already happening .

Looking to the future

However, understanding the present is not enough. Many of the decisions that will influence emissions in 2050 must be made far in advance, such as designing buildings, investing in energy infrastructure and car manufacturing plants (Section 1). These decisions should ideally be robust to a wide range of possible future outcomes, such as faster- or slower-than- expected deployment of zero-carbon energy supplies, or higher or lower loading requirements for buildings in use. When this is not done

well, the result is the situation described in Section 2.3, where structural designs are routinely excessively sized, leading to proportionally excessive carbon emissions. In contrast, it has been shown that an initially-smaller design that allows for reinforcement to be added to beams in future, if needed, would lead to lower lifetime emissions .

There are many possible pathways to zero emissions in 2050, and different reports can reach very different conclusions from by focusing on different scenarios. To provide clarity on our options to reaching Absolute Zero, we need to compare different proposals on a common basis and highlight the different starting assumptions that lead to different conclusions (see box story overleaf for an example).

Getting better information

Despite these important roles that information about our use of resources plays, the data we have is patchy and disconnected. There are two basic ways the situation can be improved: collecting better data, and making smarter use of the limited data we do have.

The UK Government's Resources and Waste Strategy has recognised that 'lack of reliable data on the availability of secondary materials is cited by industry as a barrier to their use', and proposes a National Materials Datahub to address this issue by providing 'comprehensive data on the availability of raw and secondary materials, including chemicals, across the economy to industry and the public sector, and by modelling scenarios around material availability'. The Office for National Statistics is leading the initial development of such a Datahub. As well as official statistics such as these, there is a large body of evidence contained in academic work which is currently difficult to access. Efforts towards Open Science practices ins fields such as Industrial Ecology are starting to improve the discoverability and reusability of this knowledge.

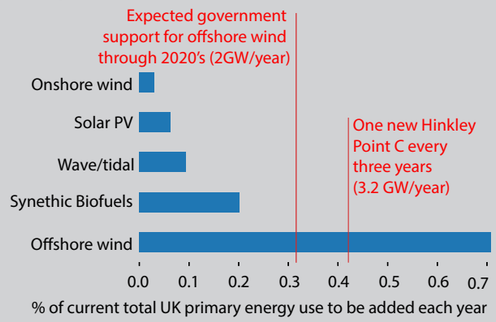
Better information will also be needed within and across supply chains, but there are challenges that will have to be overcome before this can be achieved. The first

Why aren't all plans for zero emissions the same?

Several reports have presented scenarios for how we could achieve net-zero emissions in 2050, such as the Centre for Alternative Technology's "Zero Carbon Britain" report. Unlike the need to reduce absolute energy use described in this report, they find instead that "industrial energy use is expected to remain similar to current levels". How is it possible to reach such a different conclusion on the same question?

It is easier to see the differences by looking at the different assumptions made about the energy system. The figure on the right shows the deployment rates implied by their scenario, together with some reference points to provide context. The Zero Carbon Britain report has much more optimistic assumptions about the deployment rates of renewable generation technologies, especially very early-stage technologies such as producing liquid fuels from biomass – which has not yet been proven at commercial scale – and wave & tidal generation. Assumed deployment rates for offshore wind are also high, requiring a doubling in the speed of installation envisaged in the Governments plans for support through the 2020s.

Figure 3.3: Rates of increase in "Zero Carbon Britain"



is information gathering: it is still not normal practice by suppliers to gather information on all facets of their manufacturing process. Secondly, for business to share collected data with rest of the chain rather than storing in silos. Current corporate practices mean information is often not shared even with different groups within the same organisation let alone with "outsiders". In the information age, industry has remained closed to information outflow. This may be attributed to good reasons, but the achievement of Absolute Zero requires, possibly above all else, the will to cooperate. The final challenge is analysis of the data and making sense of it. Gathering, storing, processing and presenting data is an energy intensive and expensive task, therefore currently most organisations do not have the appetite to undertake this without proven returns.

Digital tools can potentially help to enable this position. A universal and global approach to IP law and the tracking of information using technologies such as blockchain can greatly increase the confidence of organisations into opening their doors and sharing more of their information. By doing so it is possible to dramatic reduce resource duplication whilst enhancing visibility of resource usage. This could allow businesses to make long-term strategical decisions that lead to higher profitability whilst reducing energy usage and CO_2 production.

Key Message: Good information is critical to transitions in individual behaviour, business operations and in supporting government action, but there are challenges to overcome in collecting and communicating the required information effectively to support decisions and influence behaviour.

4. Opportunity

Key Message: Absolute Zero requires societal change. This will provide opportunities for growth in business, education and research, governance and industrial strategy. To achieve zero emissions we must only pursue the right opportunities and restrain activities which are no longer compatible with a zero emission society.

4.1 Opportunities in business:

This report has revealed an overwhelming wealth of innovation potential for businesses – but not in the area that dominates current discussion about mitigating climate change. Carbon Capture and Storage or Utilisation and "the Hydrogen economy" are important development opportunities and may be significant beyond 2050, but won't play any significant part in national or global emissions reductions by 2050, because implementation at meaningful scale will take too long. Instead, taking the target of Absolute Zero seriously requires a massive expansion of wind and solar power generation, along with the infrastructure required to install, manage and deliver this power and the fertile supply chains of material extraction, production, construction and manufacturing.

The key innovation opportunities revealed in this report are not about how we generate energy, but how we use it. Meeting the target of Absolute Zero requires adapting to using around 60% of the energy we consume today, which without innovation will require restraint. However, section 2 of the report has revealed a tremendous space for business innovation and growth in expanding the benefit we receive from energy use. For the past century, our economy has grown based on an assumption of virtually unlimited energy supply without consequences. Unsurprisingly, this has led to extremely inefficient use – for example with cars weighing around 12 times more than the people within them. The more rapidly the UK commits to delivering its legally binding target, the greater the benefit it will extract from business innovation opportunities. Without question, some incumbent businesses such as the fossil fuel industries, will decline and inevitably they currently spend the most money on lobbying the government to claim that they are part of the solution. This is unlikely.

Instead, future UK growth depends on exploiting the opportunities created by the restraint of Absolute Zero. For example:

- All current aviation activity will be phased out within 30 years, which creates an extraordinary opportunity for other forms of international communication (for example using the technologies of today's gaming industry to transform today's backwards-looking video-conferencing), for the travel and leisure industry to expand more localised vacations and for developments in non-emitting mid-range transport such as electric trains and buses
- The markets for electric cars, electric heating at all scales and temperatures, electric motors at all scales, building retrofit and thermal control are certain to grow at rates far ahead of the recent past. Electric cars comprise a small fraction of new sales today, but under current regulation will, by 2040, have captured 100% of the market. Given the total energy supply constraint of Absolute Zero, the clear evidence of Fig. 2.6 is that the total market will either contract or shift rapidly towards smaller vehicles – this is a fertile and under-populated space.
- Cement and blast furnace steel production will be illegal within 30 years, yet our demand for construction and manufacturing will continue. To meet this demand our supply of bulk materials must transform and there is high-volume innovation potential for non-emitting cement substitutes, for technologies to support high-quality steel recycling, and in the open space of "material efficiency": using half the material per product and keeping the products in use for twice as long.

Beyond the 2050 target of Absolute Zero, technologies that exist at early development stages today may expand into valuable business streams. These include:

- Carbon Capture and Storage or Utilisation applied to fossil fuel power stations, steel or cement production.
- The "hydrogen economy" once there is spare capacity in the supply of non-emitting electricity
- Other forms of electrical transport, including shipping and aviation

The 100% target of the Climate Change Act creates an extraordinary opportunity for UK business to develop the goods and services that will be the basis of a future global economy. However, the biggest commercial opportunities are not breakthrough but incremental developments from today's technologies.

4.2 Opportunities in welfare and education

Today's secondary school entrants will be 43 in 2050. At that age, they will be in leadership positions, so the obvious question is what skills they should be developing now and in their subsequent higher-education years to underpin their decision-making abilities in a very different future world? The legacy of education is surely to know that it is the quality of the questions which one is able to ask which will lead to success. Asking the right questions is a sign of deep education, while answering these questions is an altogether easier proposition even if research is needed.

How do we move from answering questions as the staple of education to asking questions as the hallmark of a necessary education for future uncertainty? Climate change provides us with exactly this opportunity. Some of the current syllabi in secondary schools will be irrelevant in future, and there will be new skills that school children will require. The same is true in universities, both in teaching and in research, where a clear distinction must be made between mitigation actions that can be deployed today through chosen restraint and innovations that might ease the challenge of restraint in future. The former implies hard decision-making, while the latter implies real opportunity.

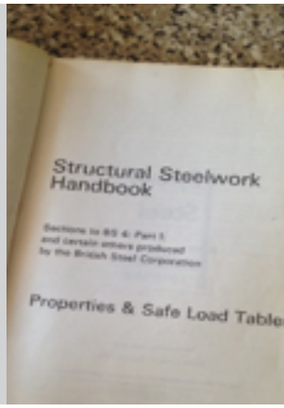
Starting with the difficult decisions, an educational setting should provide a timeline for actions to be taken by humanity in order to ensure that we hit our carbon-reduction targets by 2050. Plans cannot merely relate to actions. They must also relate to the timings of such actions, as any Gantt Chart does. By working backwards from 2050, and sequentially working out the order and timing in which key mitigation actions need to be taken, a roadmap for the necessary restraint can be established. Across the secondary school system, this roadmap is essential in eliciting the questions which will inevitably come from the school children. This will enable an exploration of real change in the mind sets of those who will need to embrace change more than ever before later in their lives. Huge questions will emerge, such as: will internal-combustion engines disappear, will aeroplanes disappear, will meat-and-dairy agriculture disappear and will we need to stop building things? By empowering school children to realise that asking the huge questions is appropriate, we will enable change to be embraced through education. The timing of the change should lead to questions of transition towards electrification, or the trade-offs between energy and labour in delivering services across a whole range of economic activities, for instance. What are the implications for consumption or ownership in a changing society, and how can we ensure that material use down to the finest granularity is all encapsulated in circularity?

Across the education system, we should be seizing the opportunity for the next generation to grow up with 'best practice': from the food available in schools, the way children get to school, to the way school buildings are used. All schools could immediately switch to providing meat-free meals – reducing emissions and promoting healthy eating. Existing efforts to change travel habits aimed at avoiding local air pollution around school gates can be extended to support parents and children in low-carbon travel to school wherever possible. Many schools already feel the need to keep heating temperatures low in an effort to make severely constrained budgets balance, which is a side-effect that could be standardised across the system to help establish the normality of lower-energy, lower-temperature heating setpoints.

Changing Building Design Practices through Education in the 1970's

In the 1970's, British Steel saw an opportunity to expand their market for structural steel sections, by persuading UK clients and the construction supply chain to switch from concrete framed buildings (which remain more common in many European countries even today) to steel framed buildings, like the one illustrated on page 35. Instead of seeking Government support to subsidise or legislate to support this change, they instead developed high quality teaching material and supported the development of new courses in all major civil engineering degree courses about design with steel. As a result, the next generation of graduate civil engineers entering the profession were equipped to use more steel, and expected it to be more normal practice.

This suggests an opportunity to develop teaching material that reconfigures society to adopt new approaches to thriving in a zero carbon economy, by changing the way we live and work.



Looking beyond the need for this kind of restraint in the short term, there are enormous opportunities in education which we could be embracing now to ensure that when the painful period of mitigation nears an end, we have an educated population ready to take advantage of the zero-carbon era. We do not have the luxury of time to wait for graduates to emerge who know something about future possibilities. We need to exploit the creativity, intelligence and ideas of our students before they have graduated. But what are the innovations which we should be teaching? We are still researching them, and research takes time.

A potential solution to this unwanted time dependency is Vertically Integrated Projects (VIP), a concept developed by Georgia Tech, and which is now also operating successfully at the University of Strathclyde in the UK. In essence, undergraduate students across all years of study are involved in major inter-disciplinary research projects, each of which is aimed at a long-term complex research question. Strathclyde ensures that the 17 UN Sustainable Development Goals are central to their VIPs. In this way, undergraduate students not only learn key skills for the future, but they are indeed themselves creating knowledge for all simultaneously. It is the combination of empowerment, inter-disciplinarity, huge research questions, confidence and space to explore without fear of failure which brings this concept alive. In an era of extraordinary change and equally extraordinary opportunity, it feels right and proper that the most fertile brains are exploited and enriched in such a manner.

There are questions which the era of restraint begs concerning research and its funding in universities and companies. Is it right, for instance, to be funding research using public funds which includes technology-developments which we know are not aligned with the 17 UNSDGs? Examples might include trying to squeeze out efficiency gains in 20th century technologies or researching products which rely on scarce materials.

Bold decisions are needed by schools, universities and funding bodies if we are to galvanise education and action towards rapid mitigation, followed by innovative opportunity. Across the span of education and research, areas of importance highlighted by this report include:

- Technologies and their constraints in efficient use of electric motors and electric heating
- The trade-offs between energy and labour in delivering services across the range of all economic activities
- Understanding of welfare dependent on self-actualisation rather than consumption or ownership
- Maximising the value of secondary materials and the realities of reduce/re-use/recycling/ "circularity" etc.
- Renewable generation and the system of its efficient use.

The opportunity in education spans from preparing for the restraint required to achieve Absolute Zero to preparing for the longer-term transformation of prosperity beyond 2050. What could a world look like without cement, internal combustion engines or aeroplanes? We need to educate students for this new reality, and embrace the opportunity, rather than the threat, which this reality offers.

4.3 Opportunities in governance

The Olympic Games was one of the biggest government projects which was delivered on time and to budget. It was a great success and a source of national pride. There are parallels between hosting the 2012 Olympic Games and delivering Absolute Zero. Both commitments were made on a world stage where failure to deliver would result in national embarrassment; both projects require collaboration of multiple government departments, industry and the general public; and both require delivery processes and structures to be built from scratch. We managed to overcome these challenges for the Olympics, but delivering Absolute Zero has additional challenges.

To achieve our emissions goal we have to sustain momentum over a longer timespan than for the Olympics. We also have to consider life beyond 2050, what is the legacy of the net-zero emissions project? The Olympic legacy has been criticised for under delivering, so we must do better this time to ensure society can thrive in a zero emissions world beyond 2050. When we hosted the 2012 Olympics we could draw on the experiences of historical Olympic Games to inform decisions being made, but no country has met a zero-emissions target before, there is no precedent for us to follow. Finally the 2012 Olympic developments generated growth in the delivery of new and improved infrastructure and services. Meeting the net-zero emission targets will generate growth in some industries, but will also require the decline of others, this is likely to be met with resistance as those who benefit from the status quo resist change.

The London Olympics highlighted the following key lessons that could be transferred to emissions targets:

- Form a responsible body in government
- Limit innovation to knowledge gaps to reduce risk
- Maintain a unified cross party vision
- Have a protected and realistic budget
- Invest in programme management & delivery with discipline on time and scope change
- Empower people, with the right skills and track record to deliver against clear responsibilities
- Ensure accountability, with scrutiny and assurance given when risk is identified.

This section attempts to explore the first three of these lessons, the most relevant to Absolute Zero commitment.

Responsible body in government:

For the 2012 Olympics an executive non-departmental public body (NDPB) called the Olympic Delivery Authority (ODA) was established to deliver the infrastructure and venues required for the Olympics. In parallel the London Organising Committee of the Olympic and Paralympic Games (LOCOG) was established as a private company limited by guarantee to fund and stage the Games. The government set up the Government Olympic Executive (GOE) within the Department for Culture, Media & Sport. The GOE was responsible for other elements of the games, such as transport and security, as well as overseeing the ODA and LOCOG. Although the governance structures were considered to be complex, it has been reported that they allowed quick decision making and ensured people remained engaged throughout the delivery process.

Figure 4.1: Olympic-style governance structure for UK Climate Emergency Response:

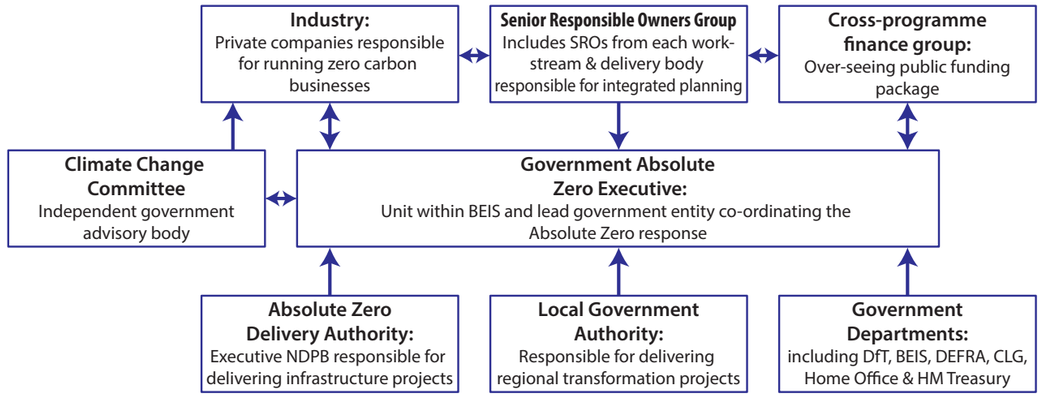


Fig. 4.1 gives an example of how this structure could be applied to delivering Absolute Zero. The proposed Government Absolute Zero Executive would be even more critical since it would be required to coordinate multiple industries and organisations, rather than just two delivery bodies as was the case in the 2012 Olympics. The governance structure proposed in Fig. 4.1 would enable fast decision making and accountability to meeting interim goals, which is essential if we are going to meet the 2050 zero emission targets.

Limit innovation:

The Government Olympic Executive deliberately limited innovation to fill knowledge gaps. This move was considered to be counter-intuitive, but it was successful. Relying only on proven technologies reduced the risk of failure and avoided the temptation to use the Games to showcase risky innovation. Although the Olympics did not innovate new ways of doing things, it did require existing activities to be scaled up to meet unprecedented demand. As Jeremy Beeton, Director General of the Government Olympic Executive explains "It was a whole new business model for London." This scaling up of proven technologies and systems was seen as a risk in itself. This lesson should be transferred to the task of meeting the 2050 zero-emission targets. We have identified in this report 'bright spots' where best practice exists and could be scaled up, if we apply the Olympic approach, this is enough of a risk, and further innovation should be limited. That said, we don't currently have all the answers to transition to a net-zero society and some innovation will be necessary, but approached with caution.

Cross party vision:

The delivery of the 2012 Olympic Games was supported by a unified cross party vision which was maintained through regular progress reports. This enabled stability throughout government changes which allowed the project to maintain momentum. The UK's approach to climate change does not currently have a unified cross party vision. For example in 2019, the Labour party proposed moving the zero-emissions targets to 2030. Whilst parties argue over goals and targets, actions are not being taken and we fall further behind on the journey to zero-emissions. It is essential that government generate a unified cross party vision to emulate the success of the 2012 Olympics which was able to create clear roles and responsibilities which fostered collaborative problem solving, not blame shifting.

If we are to learn from our previous successes, the net-zero target is more likely to be achieved through the establishment of the Government Absolute Zero Executive and the associated Delivery Authority with cross party support. The Executive should set a strategy which is realistic and risk averse, without over-reliance of innovation.

4.4 Opportunities for Industrial Strategy in the UK

With a legal target, now set by the UK government, to achieve net-zero emissions by 2050, UK business are developing organisational strategies to ensure they will prosper in a zero emissions business landscape. This report has shown how placing resource efficiency at the heart of industrial strategy can enable businesses to prosper, but this requires significant changes in the products, production processes and supply chain systems which currently make up the industrial sector.

The UK government has invested £5m in the UK FIRES research programme, bringing together the academics from six universities who have written this report with businesses across the supply-chain in a 'Living Lab'. The subscribing industrial partners pose strategic challenges to the academic research team and test emerging solutions in practice.

UK FIRES research will support businesses in developing industrial strategies to achieve zero emissions in key four areas illustrated in Fig. 4.2:.

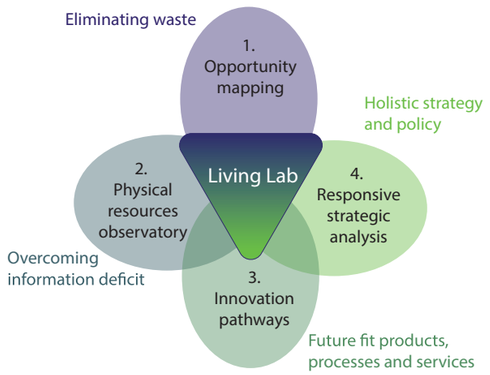
1. Opportunity mapping will identify new methods of design and manufacture which improve on existing best practices. Software tools to enumerate all options for design and delivery of resource intensive goods with today's technologies will be developed and commercialised.

2. The tools of recent advances in data science will be applied in a new Resource Observatory, to provide the highest-resolution insights into the UK's use of resources, with new metrics, scenarios and search tools used to identify opportunities for valuable innovation and efficiency gains. These tools will give UK FIRES industry partners foresight in decision making.

3. Through specific case studies of process, product and service innovation, the UK FIRES consortium will seek to define the innovation pathways by which the new practices of resource efficiency can be the basis of thriving UK businesses. The Living Lab industrial partners will be supported to exploit these opportunities in practice.

4. To support holistic industrial strategies and supply chains UK FIRES researchers will create responsive strategic analysis tools. Living Lab industrial partners can then apply these findings through the generation of new business models in collaboration with the UK FIRES Policy Champion.

Figure 4.2: UK FIRES programme structure



The output of the UK FIRES Living Lab collaboration will be published in quarterly reports, made available for government and industry, to provide reliable information to inform the development of their net zero industrial strategies. Focus themes for future Living Lab reports are now outlined.

UK FIRES connections

UK FIRES aims to provide data, tools, experience and analysis to support its partner companies in specifying new business models, diffusing innovation, giving holistic foresight to new opportunities and improving best practice as they pursue Resource Efficiency for a net-zero industrial strategy.

UK FIRES members can access the resources of the £5m programme through:

- Quarterly meetings of the Living Lab, in which members across the bulk materials supply chains specify target challenges for future work, support current activity and provide feedback on the application of programme insights in practice.
- Early access to emerging analysis of strategic opportunities
- Shared or dedicated PhD students applying the collective insights of the UK FIRES team to specific commercial contexts
- Pilot testing of new tools developed in the research programme
- Shaping the agenda and participating in the Annual UK FIRES Resource Efficiency Forum.

For more information contact info@ukfires.org.uk

Notes to the figures

Figure 1.1: Assuming an additional 400 TWh/year is needed by 2050, to be supplied by offshore wind, we need to have 115 GW of offshore wind capacity operational by 2050 (assuming an approximate capacity factor of 40% for offshore wind). The Crown Estate estimates that projects with seabed rights being awarded in 2021 would become operational by 2030, so all projects needed for 2050 would need to be started by 2040. Although current capacity is 9 GW, there is an additional 25 GW already in the pipeline. Therefore new projects need to be established and built at a rate of 4.5 GW/year for the next two decades.

Figure 1.3: Data from the International Energy Agency (IEA, 2018) with data on CCS installations at power-stations from the Oil and Gas funded pro-CCS lobby, Global CCS Institute.

Figure 1.4: This analysis by Vaclav Smil (2014) looks at global deployments of the three major fossil fuels, relative to total world energy demand at the time. Some faster transitions have occurred in individual countries, as shown in the box story on page 3.

Figure 1.5: The data in this figure come from a survey of academic reports by Gross et al. (2018) on the introductions of a range of new technologies - which generally showed that energy technology changes are among the slowest to reach full deployment.

Figure 1.6: Sectoral breakdown of UK energy demand from DUKES (2019); UK domestic internal temperature history from Official Statistics (2014); European car weight (and similar trends for all other regions) from the Global Fuel Economy Initiative a partnership with the International Energy Agency and others.

Figures 1.7–1.8: All constructed using data from DUKES (2019). n.b. there are many ways of calculating the equivalence of fuels - typically, the units of "Mega-tonnes of oil equivalent" are used, but this is not obvious when comparing primary electricity (nuclear or renewably powered electricity) which is not the result of conversion in a power station. We have attempted to be consistent in reporting the Mtoe equivalence of total UK energy demand.

Figure 1.9: Constructed with yearly data on electricity supplied in the UK from DUKES (2019). Electricity generated via non-emitting sources is shown as stacked lines whereas electricity generated from coal, gas and oil is plotted in a separate line.

Figure 1.10: The cost figures represent the weighted average of the levelized cost of electricity of commissioned solar and onshore wind projects in the United Kingdom and were obtained from IRENA (2018). For solar photovoltaic generation only cost figures after 2010 were reported. The figures were converted from US dollars to Pound sterling using yearly average exchange rates. The power density points for onshore wind were obtained using the power density of 61 wind farms commissioned between 1992 and 2007 compiled by Mackay (2009). These data-points were averaged by year of commissioning using installed capacity as averaging weight. The installed capacity and commissioning dates were obtained from Department for Business, Energy & Industrial Strategy (2019). The power density points for solar photovoltaic were estimated using best available cell efficiency data provided by National Renewable Energy Laboratory (2019) for multi-crystalline Si Cells in conjunction with the UK's annual insolation data from Photovoltaic Geographical Information System (2017) and a performance ratio of 84 % obtained from National Renewable Energy Laboratory (2013).

Figure 1.11: This chart was constructed using 2005 global energy data supplied by the International Energy Agency, and multiple sources to estimate the allocation of energy to devices and "passive systems" - the equipment (such as a car or house) in which the final form of energy (typically mechanical work or heat) is exchanged for a service. The chart is from Cullen et al. (2010), which has a lengthy Supplementary Information file giving every detail of the estimations. It is currently arduous to update this form of analysis - and a target of the UK FIRES research programme is to use the emerging techniques of Data Science to make this easier - but we assume that the proportions of energy use have remained approximately similar from 2005 to today.

Figure 1.12: Data taken from Haberl et al. (2007), subject to uncertainty due to definitions and the need for estimation of un-measurable data.

Figure 1.13: all the values represent "real world" efficiencies of conversion devices. The efficiency of electric heater, light and electronic devices was obtained by Cullen and Allwood (2010). The efficiency of electric battery charging applies to charging road vehicles and was obtained from Apostolaki-Iosifidou et al. (2017). The efficiency of heat pumps is the average of all the values reported by Shapiro and Puttagunta (2016) who quantified the coefficient of performance of these devices during use in residential buildings. The remaining values were obtained by Paoli and Cullen (2019).

Figure 1.14: Figure 1.14: This Sankey diagram was obtained using UK energy consumption data for 2018 from National Statistics (2018) and the conversion factors of figure 1.13. The data is disaggregated by energy type and sector. The total electricity demand was scaled to account for population growth using the predictions from National Statistics (2019) and the distribution losses from OECD/IEA (2018). In addition to the efficiencies of figure 1.13, the efficiency of charging electric car batteries was taken from Apostolaki-Iosifidou et al. (2017).

Figure 1.15: This analysis, building on the energy diagram of fig. 1.11 was developed in order to provide clarity for the IPCC's 5th Assessment Report, and based on global emissions data for 2010 taken from the EU's EDGAR database of global emissions. The original analysis was published as Bajzelj et al (2013) but has been modified here to clarify the difference between emissions that occur as equipment (cars, boilers, lights) are used, and those that occur in industry when making equipment that lasts for more than one year. The UK FIRES programme is largely concerned with these industrial emissions, so clarifying the way that stock of goods in service (and therefore their requirements for energy inputs) evolve over time, is of critical importance to understanding how to develop an Industrial Strategy compatible with Absolute Zero.

Figure 2.1: This figure is a summary of the analysis leading to figs. 2.2, 2.4, 2.11 and 2.19.

Figure 2.2: Today's values on energy use in buildings were obtained from UK energy statistics (HM Government, 2019). The values in the second column were calculated using the method described in the notes for Figure 1.13 and the efficiency values estimated by Cullen et al. (2010). The values in the third column were calculated considering the efficiency improvements of better insulation of roofs and attics, and the installation of double-glazed windows estimated by the IEA (2013), considering the number of surviving buildings in 2050 estimated by Cabrera Serrenho et al. (2019).

Figure 2.3: Impact of new buildings and retrofit from Cabrera Serrenho et al. (2019) and IEA (2013), use of heat pumps for space heating (MacKay, 2008), Appliance efficiency improvements (ECUK, 2019, table A1).

Fig 2.4: Today's values on energy use in transport were obtained from UK energy statistics (HM Government, 2019) and IEA energy balances (IEA, 2019). The values in the second column were calculated using the method described in the notes for Figure 1.13 and the efficiency values estimated by Cullen et al. (2010). The values in the third column were calculated considering no international aviation, the substitution of domestic shipping and aviation by rail, a reduction of energy use in passenger road transport to 60% of current levels (as demonstrated in Figure 2.6) and a reduction of 30% in road freight energy demand (Dadhich et al., 2014).

Figure 2.5: Emissions factors from the BEIS Greenhouse gas reporting conversion factors 2019. Equivalent energy intensities calculated using the BEIS values for fuel CO2e intensities, apart from rail which was calculated using the CO2e intensity factor for electric traction. Radiative forcing corrections are included in the emissions intensities for flying. Data for cars are for the current average fleet of petrol cars.

Figure 2.6: Developed assuming a linear correlation between vehicle weight and fuel consumption (there is reasonable empirical support for this) and with current vehicle weight taken from fig. 1.6.

Figure 2.7: Effect of vehicle weight reduction (Cullen et al., 2011), logistical improvements (Dadhich et al, 2014), regenerative braking (Gonzalez-Gil et al, 2014), drag and rolling resistance (Cullen et al, 2011).

Figure 2.8: developed considering the number of cars purchased and discarded in the UK estimated by Serrenho et al. (2017), with full adoption of electric cars in new sales from 2025.

Figure 2.9: This is constructed from emissions intensities reported by Scarborough et al. (2014) combined with data on portion sizes and calories per portion from the UK's National Health Service (www.nhs.uk/live-well/healthy-weight/calorie-checker/). There is significant uncertainty behind the numbers in this figure - due to the difficulty of defining the boundaries of analysis for the emissions calculation, and the arbitrary size of portions - but the scale of difference between the two foods is significant.

Figure 2.10: Is taken from Bajzelj et al. (2014) as used for fig. 1.15

Figure 2.11: Current energy consumption data from ECUK: End uses data tables, 2018, split by 2 digit SIC. Where further disaggregation was needed e.g. chemicals sector, consumption was split by the according proportions in 2007, where data is provided at 4 digit SIC level. Energy embodied in net imports for steel, cement, plastics and textiles by multiplying the energy intensity of UK production by the net imports of each material; tonnage data from Allwood et al. (2019), Shanks et al. (2019), ImpEE project and Allwood et al. (2006) respectively. Energy loss in electricity production is from DUKES aggregate energy balances, 2018. Energy for direct fuel combustion was converted to electricity using the relevant efficiency

values provided in Figure 1.11. Demand reduction interventions: 1) reduce scrap in metal processing to half of the current level, i.e. half of the savings identified in Milford et al. (2011); 2) reduce metal consumption by 20% by avoiding over-design of metal products, consistent with Section 2.3, Section 2.1 and Allwood and Cullen (2012); 3) A 75% cut in cement output based as described in Section 2.2; 4) Life extension of cars, clothes and industrial goods, reducing output of these products by 40%, 45% and 40% respectively. Proportions of steel and aluminium usage as per the global data provided in Allwood and Cullen (2012). 5) Reduction in plastic packaging by 25%; in the UK plastics packaging is 2.2Mt out of 6.3Mt total consumption estimated from the ProdCom database; 6) A 25% cut in fertiliser use, half of the reduction identified for Netherlands in Section 2.2; 7) Reduction of food waste leading to a 3% cut in output in the food processing industry as per the WRAP Courthald Commitment; 8) More efficient use of electricity in industry by improving efficiency of motors, heat pumps for space heating, process heating and lighting from 60% to 80%, 104% to 400%, 80% to 90% and 13% to 15% respectively, consistent with Cullen and Allwood (2010).

Figure 2.12: Original analysis for this report developed by C.F.Dunant

Figure 2.13: Developed from Cooper et al. (2014).

Figure 2.14: Original version of this figure published in Allwood et al. (2012) modified here to show primary production from blast furnaces declining to zero in-line with the zero emissions target.

Figure 2.15: Developed from Daehn et al. (2019)

Figure 2.16: The flows of plastics in the UK were estimated from the UK trade statistics (Eurostat, 2018), using a systematic allocation of trade product codes into the various stages of the supply chain, and by estimating the plastic content and application for each produce code.

Figure 2.17: Developed from Shanks et al. (2019

Figure 2.18: A survey of structural engineers, MEICON showed that, in general, structural engineers are prepared to over-design structures routinely in order to pre-empt any possible later changes to the brief, to deal with design risk and to cover for the possibility of construction error. Material efficient design, for example using fabric form-work, could allow substantial reduction in over-use without any increase in risk.

Figure 2.19: Current energy consumption data from ECUK: End uses data tables, 2018, split by 2 digit SIC, and where further disaggregation needed (e.g. separating primary and secondary wood processing) 2007 data at 4 digit SIC level. Energy loss in electricity production, conversion of direct fuel combustion to electricity and demand reduction interventions are all as described in Figure 2.23.

Figure 2.20: Allocation of emissions from global materials production to the six key sectors based on material flow analysis of steel (Cullen et al., 2012), cement (Shanks et al, 2019), Aluminium (Cullen and Allwood, 2013), plastic (Allwood et al, 2012), Paper (Counsell and Allwood, 2007), food (Bajzelj et al. 2014)

Figure 2.22: This data is made publicly available by the car industry. Horton and Allwood (2017) review the data, and explore several options by which this form of material inefficiency could be addressed.

Figure 2.23: Manufacturing energy efficiency imporvements (Paoli and Cullen, 2019), scrap metal reduction (Milford et al, 2011), reducing over-design and ilfe-extension (Allwood & Cullen, 2012), plastic packaging (Lavery et al, 2013), food waste (WRAP, 2018)

Figure 2.24: The proportions of losses here are indicative and based on data in Li et al (2016). The actually losses vary according to the way the hydrogen is stored and the precise pattern of demand by which electricity is extracted from the fuel cell.

Figure 3.3: The Zero Carbon Britain (Allen et al, 2013) report sets out a scenario for energy supply in 2050. We have calculated the amount that energy generation from each source would have to increase in every year from now to 2050 to achieve the target. Increases are presented as a percentage of current UK primary energy demand of about 2200 TWh (BEIS, 2019). Expectations for Government support for offshore wind in the 2020s are from the Crown Estate (2019), converted into generation values with a representative capacity factor for offshore wind of 40%. A review of Biomass to Liquid systems for transport fuel production reports that no commercial scale plants are yet operating (Dimitriou, 2018).

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Absolute Zero: some short-term restraint in our use of energy, but no restraint whatsoever in what we most enjoy...









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North Herts is about to get another 10,000 homes by 2031 – probably mainly commuters to the south placing even more pressure on the two bottlenecks at Welwyn.

1 Did you know North Herts trunk road lanes are like a palm tree. 20 trunk road lanes radiate northwards out of the county while only 4 lanes of the A1M feed from the south. (4 on the A505, 2 on the A507, 6 on the A1M, 4 again on the A505 etc etc. We require 4 lanes northbound on the A1M at Welwyn and 3 lanes southbound plus hard shoulders – not a Smart update compromise. Although not in North Herts this bottleneck impacts significantly on the life of those in North Herts. This council needs to make these views firmly known to Herts County Council

2 The railway tracks to the north are 6 fold while there are only 2 from the south at the Welwyn viaduct. HS2 is unlikely to significantly relieve pressure on this bottleneck. Many moved to North Herts on the availability of a 25 minute seat into London. We must have this expectation returned.

3 A high proportion of these 10,000 new home owners will require station parking for which there is no provision in the Local Plan. A parking requirement for each station should be established and the appropriate rail authority obliged to provide it.

4 Here in Letchworth, a multistorey carpark over the top of the railway would relieve this problem as well as the towns commuter parking blight. Such a carpark could be built in the railway cutting adjacent to the station and possibly with part funding from a levy on the new housing. Building over the top of railway lines is probably the least harmful environmental option.

There may well be fewer privately owned cars in the future - with driverless taxis and buses etc - but there is likely to be more car journeys. Consequently any road or rail issue today will still be a problem in 50 years time if not resolved so please give these transport issues priority.

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