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Abstract

Current anthropogenic climate change is the result of greenhouse gas accumulation in the atmosphere, which records the aggregation of billions of individual decisions. Here we consider a broad range of individual lifestyle choices and calculate their potential to reduce greenhouse gas emissions in developed countries, based on 148 scenarios from 39 sources. We recommend four widely applicable high-impact (i.e. low emissions) actions with the potential to contribute to systemic change and substantially reduce annual personal emissions: having one fewer child (an average for developed countries of 58.6 tonnes CO₂-equivalent (tCO₂e) emission reductions per year), living car-free (2.4 tCO₂e saved per year), avoiding airplane travel (1.6 tCO₂e saved per roundtrip transatlantic flight) and eating a plant-based diet (0.8 tCO₂e saved per year). These actions have much greater potential to reduce emissions than commonly promoted strategies like comprehensive recycling (four times less effective than a plant-based diet) or changing household lightbulbs (eight times less). Though adolescents poised to establish lifelong patterns are an important target group for promoting high-impact actions, we find that ten high school science textbooks from Canada largely fail to mention these actions (they account for 4% of their recommended actions), instead focusing on incremental changes with much smaller potential emissions reductions. Government resources on climate change from the EU, USA, Canada, and Australia also focus recommendations on lower-impact actions. We conclude that there are opportunities to improve existing educational and communication structures to promote the most effective emission-reduction strategies and close this mitigation gap.

1. Introduction

While 195 nations have agreed to limit the global average temperature increase to ‘well below 2 °C’ under the December 2015 Paris Agreement (UNFCCC 2015), most current pathways to stay under the 2 °C limit assume the future use of unproven technologies to achieve negative emissions (Fuss *et al* 2014). This has prompted calls (Anderson 2015) for near-term, profound emissions cuts that may require changes in lifestyle choices from the high-carbon individuals estimated to produce nearly 50% of emissions (Gore 2015). National policies and major energy transformations often take decades to change locked-in

infrastructure and institutions, but behavioural shifts have the potential to be more rapid and widespread (i.e. reduced reliance on cars can begin immediately, whereas improved power plant efficiency occurs on a decadal time frame (Pacala and Socolow 2004)).

It is especially important that adolescents are prepared for this shift. They still have the freedom to make large behavioural choices that will structure the rest of their lives, and must grow up accustomed to a lifestyle that approaches the 2.1 tonnes per person annual emissions budget necessary by 2050 to meet the 2 °C climate target (Girod *et al* 2014). Furthermore, adolescents can act as a catalyst to change their household’s behaviour (Maddox *et al* 2011). While the

cumulative emissions impact of any behaviour depends both on the magnitude of the action and its behavioural plasticity (the proportion of the public likely to adopt a given action assuming the most effective intervention (Dietz *et al* 2009)), the first step to understanding cumulative impact is to know the effectiveness of the action for a single person.

Here we investigate a comprehensive suite of lifestyle choices to identify those with the greatest potential to reduce individual greenhouse gas emissions. We compare our findings with recommendations from high school science textbooks and government resources. Previous studies have already evaluated some of the most effective actions for reducing energy consumption (Attari *et al* 2010, Gardner and Stern, 2008) and mitigating climate change through personal actions (Girod *et al* 2014), though individuals have a poor understanding of which actions are more effective than others (Attari *et al* 2010). Our research builds on these studies by including additional actions that have greater emissions reduction potential but have not been previously evaluated. Our methodology makes each action comparable for individuals making the decision to undertake them, and our analysis of official educational and government materials shows the extent to which public institutions currently recognize the importance of and encourage these behaviours.

2. Methods

2.1. High-impact actions

To identify our high-impact actions, we analyzed the literature to compile a candidate list of actions for emissions analysis. To choose data sources, we first used peer-reviewed literature with a life-cycle approach where available (to analyze the impact of diet and personal vehicles), followed by government reports, grey literature or carbon calculators (green energy, aviation). We analyzed studies from all countries we could find, but in the main text only report results from developed nations (the full range of studies are available in the online supplementary materials available at stacks.iop.org/ERL/12/074024/mmedia). The choice to focus on developed regions was motivated by the higher emission and consumption levels in those regions, which demand steeper emissions cuts in order to attain the same, low per capita emissions target that will avoid dangerous planetary warming (Girod *et al* 2013).

For calculations, all actions were framed in such a way that they would take the maximum possible effect. For instance, recycling is framed as recycling comprehensively for a year, a plant-based diet is framed as avoiding all meat, and purchasing renewable energy is framed as purchasing all possible household energy from renewable sources for a year, even though it would be possible to perform these actions as half-measures.

Since the unit of analysis was the individual, we wanted country-specific data to inform the most relevant individual choices possible. Therefore, household and vehicular actions were divided by the average household or vehicle occupancy of the country where the study was performed to yield results measured in tonnes of CO₂-equivalent per year (tCO₂e per year) per individual. The types of greenhouse gases included in these calculations varied with the methodologies of the different studies or sources. We also made calculations using country or region-specific data, such as average annual kilometers travelled per vehicle in a region (except where study parameters explicitly stated alternative values), to generate final values that are representative for each study area (see supplementary materials 1).

For the action 'have one fewer child,' we relied on a study which quantified future emissions of descendants based on historical rates, based on heredity (Murtaugh and Schlax 2009). In this approach, half of a child's emissions are assigned to each parent, as well as one quarter of that child's offspring (the grandchildren) and so forth. This is consistent with our use of research employing the fullest possible life cycle approach in order to capture the magnitude of emissions decisions.

In the case of aviation, some carbon calculators made use of a radiative forcing index, which accounts for the additional warming effects of gases other than CO₂ produced during air travel. Though this results in higher estimates than if the index had not been used, the life cycle studies which we also included for aviation (and which did not use radiative forcing) provided similar final values. See supplementary materials 2 for calculations.

In practice, the emissions benefits of undertaking high-impact actions may be reduced by substitution effects (where avoidance of emissions from one action is replaced by emissions from another action) and rebound effects (where reduced consumption in one area leads to increased consumption elsewhere). For instance, the emissions saved from living car-free may be lower than we calculated if public transit replaces car travel instead of biking or walking (living car free represents all the emissions associated with the life cycle of owning a car in our methodology). But even if the number of kilometers travelled remains constant, a switch from driving a sedan to taking public transit has been shown to reduce emissions by 26%–76% (Chester *et al* 2013). Since data that included rebound effects were only available for some actions, we excluded rebound effects to maintain comparability between actions.

2.2. Textbook analysis

Textbooks are a useful indicator of the content that students are receiving in classrooms; they are based on government-mandated curriculum documents and serve as a resource for both students and teachers. This may be especially true for subjects such as climate

change where a teacher is more likely to be uncomfortable with the material (Kim and Fortner 2006, Chambers 2011). Ten textbooks used in seven of Canada's ten provinces were therefore analyzed (see supplementary materials 3).

To determine which science textbooks are in use in each province we relied on the experience of the first author as a secondary school science teacher in Canada, and also contacted curriculum writers and educators from provinces where textbook usage could not be easily determined. The provinces covered by our analysis represent more than 80% of Canada's student population (we were unable to obtain the textbooks used by the provinces of Alberta, Manitoba, and Nova Scotia).

Only the textbook chapters directly addressing climate change were analyzed. Statements from the textbooks were identified as suggested actions when they included direct recommendations (e.g. 'eat less meat'), or were directed at the reader using pronouns such as 'you' or 'we'. Statements using 'individuals' and 'consumers' often explained sources of emissions without suggesting how to reduce those emissions, and were therefore not counted.

Due to the large number of unique recommendations found in textbooks, we grouped similar specific recommendations into various categories. For example, suggestions such as 'use cloth shopping bags' and 'purchase a reusable water bottle' would both be listed under the category 'reuse'. Where possible, these categories are the same in the analysis of textbooks and government documents. For each textbook, we recorded the frequency of each type of suggestion. In our coding system, a single sentence referring to a specific topic was given the same value as a paragraph devoted to a single topic. If a paragraph on a broad topic (e.g. household heating) included many specific suggestions (turn down thermostat, purchase a more efficient heater), then each specific suggestion was counted towards the total.

2.3. Government documents

To analyze broad societal mitigation recommendations, we chose three developed regions with high per-capita emissions and government documents available in English: Australia (average per-capita emissions of 16.3 tCO₂ per year), Canada (13.5 tCO₂ per year), and the United States (16.4 tCO₂ per year), as well as a lower-emission case, the European Union (6.7 tCO₂ per year) (World Bank 2016). We identified the most authoritative and relevant set of recommendations from that region indicating how their citizens can help mitigate climate change, contacting government representatives for clarification where multiple possible documents were found. The frequency of individual recommendations was recorded using the same methods as described in the analysis of science textbooks.

3. Results

From analyzing 148 scenarios of the climate impact of individual behaviours in ten individual countries (with some studies additionally considering the whole EU region), drawn from 39 sources, we have identified a dozen actions, including four recommended actions that are of substantial magnitude throughout the developed world (see supplementary materials 4): having one fewer child, living car free, avoiding air travel, and eating a plant-based diet (figure 1). Each of these actions was high-impact (reduces an individual's greenhouse gas emissions by at least 0.8 tCO₂e per year, about 5% of current annual emissions in the US or Australia) regardless of study parameters. They are also 'best in class'—most fully achieving emissions reductions within a given domain (e.g. car travel), and with the potential to contribute to systemic change (for example, living car-free reduces the need to build more roads and parking spaces, and supports higher-density urban design, which more efficient cars do not).

We originally hypothesized that two additional actions, not owning a dog and purchasing green energy, would also fit our criteria for recommended high-impact actions, but found both to be of questionable merit. Only two studies with conflicting results could be found for dog ownership (Eady *et al* 2011, Rushforth and Moreau 2013), so we have not included it in figure 1 (see supplementary materials 2). For green energy, researchers have described problems with double-counting in several European countries (Hast *et al* 2015), as seen in the near-zero emission reductions for Great Britain in figure 1. Still, in regions with carbon-based energy grids such as Australia and North America, green energy has the potential to greatly reduce emissions associated with home energy use, which is why we retained this action in figure 1.

Previous studies that compare the effectiveness of various actions tend to focus on moderate-impact actions (saving between 0.2 and 0.8 tCO₂e year) or even low-impact actions (saving <0.2 tCO₂e). Compare for instance two actions cited as among the most effective ways to reduce household energy usage (hang drying clothing (0.21 tCO₂e) and washing clothing in cold water (0.25 tCO₂e) (Attari *et al* 2010)) with any of the high-impact actions shown in green (figure 1). Our recommended high-impact actions are more effective than many more commonly discussed options (e.g. eating a plant-based diet saves eight times more emissions than upgrading light bulbs). More significantly, a US family who chooses to have one fewer child would provide the same level of emissions reductions as 684 teenagers who choose to adopt comprehensive recycling for the rest of their lives.

To illustrate the implications of our findings, consider that per capita emissions must reach 2.1 tCO₂e by 2050, if warming of the planet is to be kept below 2 °C (Girod *et al* 2013). Using values from

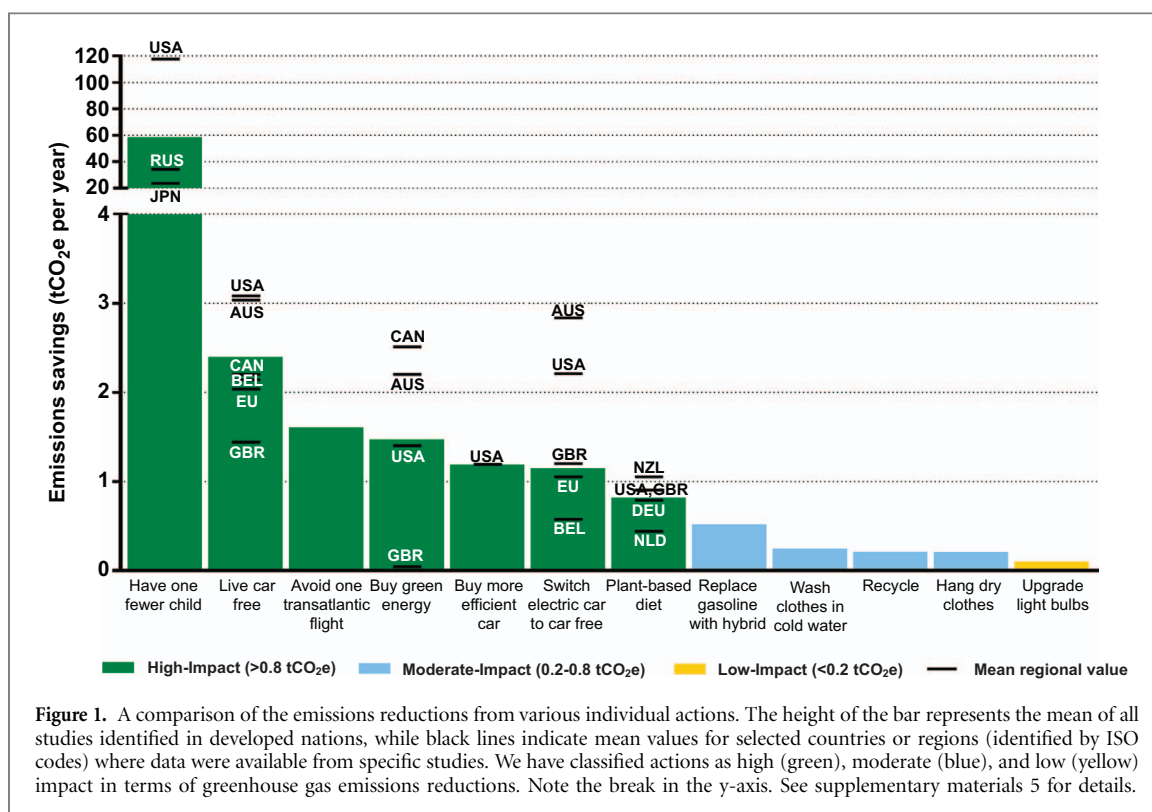


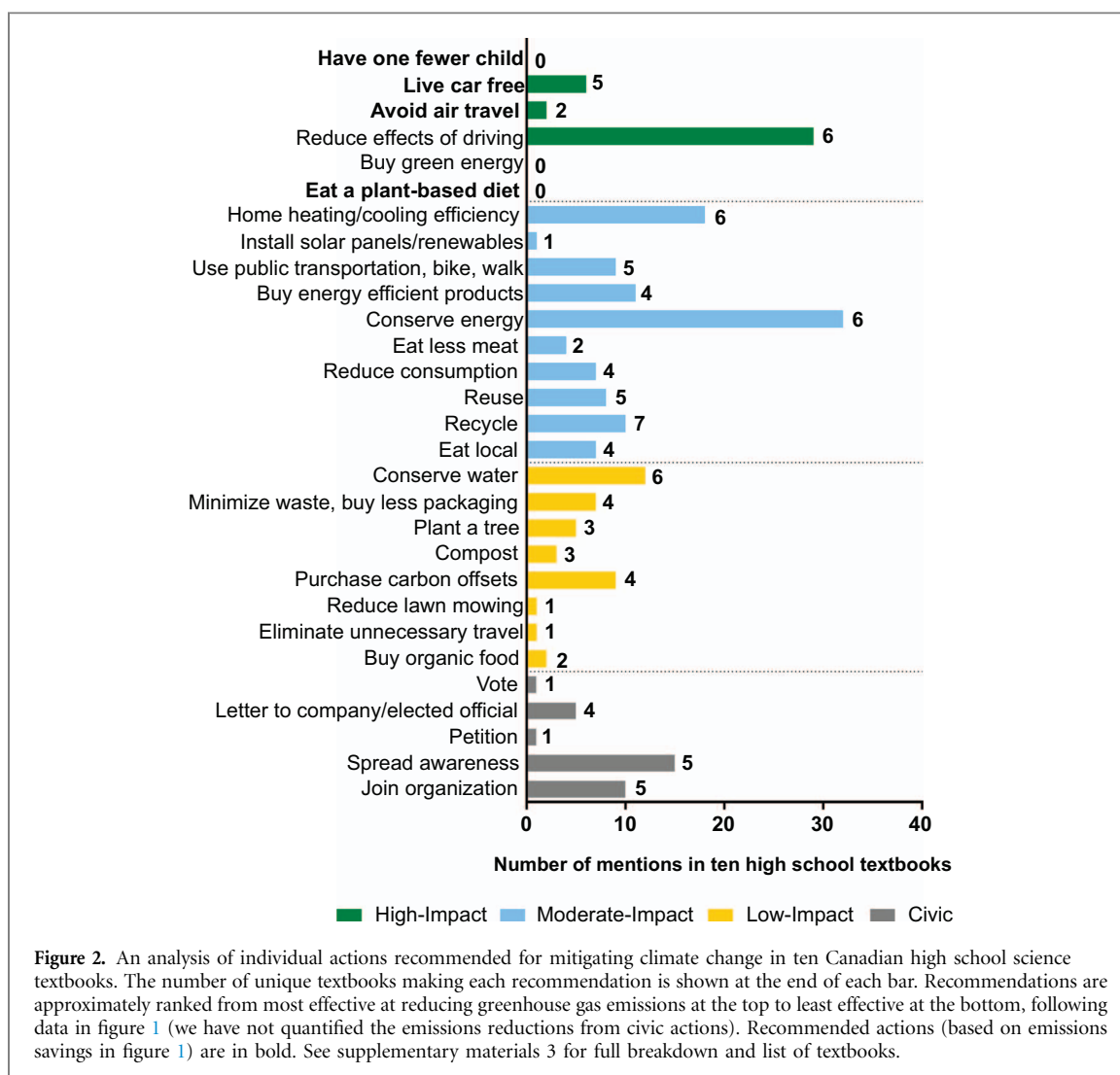
figure 1, we estimate that an individual who eats meat and takes one roundtrip, transatlantic flight per year emits 2.4 tCO₂e through these actions, exhausting their personal carbon budget, without accounting for any other emissions. It would help meet climate goals if such an individual chose to shift her or his behaviour, as technological advances may be unable to sufficiently reduce emissions from these two actions even by 2050 (Girod *et al* 2013). These two sectors are an agreed area of focus for reduced demand, as aviation is likely to be the last of all transport modes to mainstream low-carbon standards (Kivits *et al* 2010) and studies show we cannot expect to stay under a 2 °C limit without at least some shifts in diet (Hedenus *et al* 2014).

These results also highlight the greater reductions available from moving away from a polluting technology (living car-free, 2.4 tCO₂e per year lower than the baseline of a gasoline automobile) compared with using the cleanest available technology (electric cars, which still emit 1.15 tCO₂e per year on average) or incremental technological improvements (increase vehicle fuel economy by buying a more efficient gasoline car, 1.19 tCO₂e saved per year). Though electric cars may replace internal combustion vehicles and shrink the carbon footprint of the automobile, the car-based transport model itself still allows for low-density rural housing developments (Muller 2004), which are associated with twice the emissions per capita of high-density housing (Norman *et al* 2006) as well as greater consumption and energy use (Ala-Mantila *et al* 2014, Shammin *et al* 2010). A car-free lifestyle reduces traffic congestion and petroleum dependence

(Mashayekh *et al* 2012) and avoids the environmental toxicity issues surrounding electric vehicle production (Hawkins *et al* 2013), making it advantageous even in an era of low-emission vehicles. Lastly, until the emissions associated with desired services are reduced to zero, population will continue to be a multiplier of emissions (Waggoner and Ausubel 2002).

Having identified which actions are high or low-impact, it is worthwhile to know whether governments and educators are emphasizing high-impact actions. Since we consider adolescents an ideal demographic to adopt high-impact actions, we analyzed ten Canadian high school science textbooks (see supplementary materials 3) to find which broad categories as well as specific actions are currently recommended to adolescents for reducing emissions.

We found that the 216 individual recommended actions from textbooks overwhelmingly focused on moderate or low-impact actions, with our recommended actions mostly presented in a less effective form, or not at all (only eight mentions, or 4%). No textbook suggested having fewer children as a way to reduce emissions, and only two out of ten mentioned avoiding air travel (figure 2). Eating a plant-based diet was presented in the form of moderate-impact actions such as eating less meat, even though a completely plant-based diet can be 2 to 4.7 times more effective at reducing greenhouse gas emissions than decreased meat intake (Meier and Christen 2012). Similarly, methods for reducing one's impact while driving were mentioned almost 30 times, with only six mentions of a car-free lifestyle. Instead, the recommendation category mentioned in the most textbooks was



recycling (seven of ten textbooks) and the recommendation category with the most individual actions mentioned was energy conservation (32 mentions) (figure 2).

This trend of focusing on lower-impact actions is generalizable in other developed countries. We analyzed four government guides, each selected as an authoritative source for its region and found a focus on moderate-impact actions such as recycling or reducing home energy use (table 1). Except for a handful of references to the quantity of emissions saved by specific actions (altogether missing from the Canadian guide), these guides provided little information for users to discern which actions might be more effective, and therefore which to prioritize. Regarding our identified high-impact actions, no guide recommended having fewer children or eating a plant-based diet, though the EU guide did suggest eating less meat and more vegetables. Neither the US nor Australian guides suggested avoiding air travel. All government guides discussed reducing the impact of personal vehicles through buying cleaner cars or driving or maintaining them better, and all suggested increased use of cycling or public transport, but only Australia adopted the framing of a car-free lifestyle.

4. Discussion

While past research has focused on incremental behavioural changes that require minimal effort on the part of individuals (Dietz *et al* 2009), we propose to empower individuals to focus on changing the behaviours that are most effective at reducing their personal emissions. Many of these changes can be seen as desirable choices that promote a slower and healthier lifestyle (Soret *et al* 2014, Frank *et al* 2004). In addition to adolescents, it would also be beneficial for those who are already willing to make impactful lifestyle changes for the sake of the climate to be aware of which actions will be most effective.

Serious behavioural change is possible; there is evidence that younger generations are willing to depart from current lifestyles in environmentally relevant ways. For instance, the United States has seen a measurable decrease (Kuhnimhof *et al* 2013) or at the very least, delay in car usage and ownership for the millennial generation compared to previous generations (Garikapati *et al* 2016). In terms of plant-based diets, the willingness of individuals to eat less meat increases with the perceived effectiveness of this action, which suggests the need for increased

Table 1. Actions recommended in government documents to reduce an individual's greenhouse gas emissions. CO₂ reductions are based on sources from figure 1 (see supplementary materials 4), unless otherwise noted. Our recommended high impact actions are shown in bold. Results are from four government sources: 'Take Action' from Australia (Department of Industry and Science 2014), 'Top 10 Things You Can Do To Help' from Canada (Government of Canada 2012), 'Climate Action' from the European Union (European Commission, 2015) and 'What You Can Do' from the United States (EPA 2015).

Behaviour	Example	Approximate CO ₂ e reduced per year (kg)	AUS	CAN	USA	EU
<i>High Impact Actions</i>						
Have one fewer child		23 700–117 700				
Live car free		1000–5300	x			
Avoid one flight (depending on length)		700–2800		x		x
Purchase green energy		<100–2500	x	x	x	x
Reduce effects of driving	Buy more efficient car	1190	x	x	x	x
Eat a plant-based diet		300–1600				
<i>Moderate Impact Actions</i>						
Home heating/cooling efficiency	Wall insulation	180 (Chitnis <i>et al</i> 2013)	x	x	x	x
Install solar panels/renewables	Rooftop solar		x		x	x
Use public transportation, bike, walk			x	x	x	x
Buy energy efficient products	Energy Star		x	x	x	x
Conserve energy	Hang dry clothes	210	x	x	x	x
Reduce food waste	No food waste	370 (Hoolohan <i>et al</i> 2013)	x			x
Eat less meat		230 (Meier and Christen 2012)				x
Reduce consumption	Pay bills online		x		x	x
Reuse	Reusable shopping bag	5 (Dickinson <i>et al</i> 2009)	x	x	x	x
Recycle		210	x	x	x	x
Eat local		0–360 (Coley <i>et al</i> 2009, Weber and Matthews 2008)				x
<i>Low Impact Actions</i>						
Conserve water	Run full dishwasher		x	x	x	x
Eliminate unnecessary travel			x		x	
Minimize waste			x	x		
Plant a tree		6–60 (Freedman and Keith 1996)		x		x
Compost			x		x	x
Purchase carbon offsets						x
Reduce lawn mowing	Let lawn grow longer					x
Ecotourism	Use Ecolabelled accommodation					x
Keep backyard chickens			x			
Buy Ecolabel products						x
Calculate your home's footprint					x	
<i>Civic Actions</i>						
Spread awareness					x	
Influence employer's actions					x	x
Influence school's actions					x	

awareness of the most effective options for sustainable dietary changes (De Boer *et al* 2016).

However, even knowledgeable and willing individuals may not reduce meat intake or adopt other high impact actions if cultural norms or structural barriers act as obstacles. For example, western cultural norms associate meat with wealth, status and luxury (Ruby 2012) and meat consumption per capita in the richest 15 nations is 750% higher than in the poorest 24 nations (Tilman and Clark 2014). Just as cultural norms promote meat consumption, structural choices such as sprawling neighbourhoods can promote individuals' use of high carbon transport (Cervero 2002). Shifts in public policy, such as a carbon tax on

food commodities (Springmann *et al* 2016) or encouraging compact urban growth (Hankey and Marshall 2010), can address these barriers. The benefits of such policies extend beyond climate change; plant-based diets conserve biodiversity and reduce illnesses like cancer and type II diabetes (Tilman and Clark 2014) while car-free living can reduce obesity (She *et al* 2017) and airborne pollutants (Chester *et al* 2013).

Though we have analyzed the transmission of information, we do not intend to endorse the widely criticized knowledge deficit model of behaviour (Kahan *et al* 2012), which holds that people will act to prevent climate change if they understand it better.

Tested strategies for promoting individual actions to mitigate climate change have been explored elsewhere, such as showing students how to use public transit, rather than simply encouraging it (Cornelius *et al* 2014). But before these strategies can be widely implemented in classrooms, there must be accurate information to prioritize actions in curriculum documents and teaching materials such as textbooks.

Some high-impact actions may be politically unpopular, but this does not justify a focus on moderate or low-impact actions at the expense of high-impact actions. As a specific example, one textbook says ‘making a difference doesn’t have to be difficult’ and provides the example of switching from plastic bags to reusable shopping bags in order to save 5kg of CO₂ per year (Dickinson *et al* 2009). This is less than 1% as effective as a year without eating meat. Examples like this create the impression that the issue of climate change itself is trivial in nature, and represent missed opportunities to encourage serious engagement on high-impact actions.

It is possible that textbook and government writers intentionally selected low-impact actions because they are frequent and easy to perform. If so, this would likely follow the ‘foot-in-the-door technique’, a type of positive spillover where encouraging small actions is hoped to lead individuals to take more substantial behaviours later (Thøgersen and Crompton 2009). Unfortunately, empirical evidence of the spillover effect is mixed. Some interventions result in an increase in other pro-environmental behaviours but most examples of positive spillover occur between similar actions, i.e. not from small actions to substantial ones (Truelove *et al* 2014). Early results also indicate that high-commitment, pro-social behaviours are more likely to cause further positive spillover (Gneezy *et al* 2012), which supports an emphasis on high-impact actions as a way to change overall norms.

Regardless of spillover effects, some actions will doubtless have a reduced cumulative emissions impact because barriers currently limit their uptake on a large scale. But the inclusion of such actions in textbooks demonstrates the seriousness of climate change, and offers a starting point for important discussions that challenge unsustainable societal norms.

Whether the goal is to slowly change societal norms or to encourage significant personal emissions reductions, adolescence is an ideal time for intervention. The majority of the textbooks that we analyzed are aimed at Grade 10 students (typically age 16), which is the same age that most Canadians are first allowed to obtain a driver’s license (Government of Canada 2014). Adolescents can also choose their own diets, can influence family decisions on vacations (e.g. flying vs. staying local) and should be informed of the environmental consequences of family size as they are likely becoming sexually active. Though a 50-year-old

car owner with an established lifestyle living in the suburbs might be better able to adopt a recommendation to drive a more efficient car, there are qualitative (paradigm shifting of social norms) and quantitative (emissions reduction) reasons for an adolescent to instead receive the high-impact message: ‘live car free’.

It is important to acknowledge the limitations and uncertainty of the data that we have presented. We provide mean values for our recommended actions, but we do not suggest that these are firm figures universally representative of each action, but instead best estimates. For instance, a transatlantic flight will differ in emissions magnitude based on the exact distance travelled, weight of a passenger’s luggage, the occupancy of the plane, wind speed and many other variables, in addition to the differences inherent in varying assessment methodologies. Our estimations are most useful when they compare different classes of actions that vary substantially. Similarly, we have presented lists of actions (figure 2 and table 1) which are ranked approximately from highest to lowest-impact in reducing greenhouse gas emissions. Actions are placed into groups which are qualitatively similar, but may be highly variable by emissions impact. Still the differences between a high-impact and a low-impact action are considerable.

5. Conclusion

We have identified four recommended actions which we believe to be especially effective in reducing an individual’s greenhouse gas emissions: having one fewer child, living car-free, avoiding airplane travel, and eating a plant-based diet. These suggestions contrast with other top recommendations found in the literature such as hang-drying clothing or driving a more fuel-efficient vehicle. Our results show that education and government documents do not focus on high-impact actions for reducing emissions, creating a mitigation gap between official recommendations and individuals willing to align their behaviour with climate targets. Focusing on high-impact actions (through providing accurate guidance and information, especially to ‘catalytic’ individuals such as adolescents) could be an important dimension of scaling bottom-up action to the transformative decarbonisation implied by the 2 °C climate target, and starting to close this gap.

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