Published by Oxford University Press on behalf of the International Epidemiological Association
 Advance Access publication 19 April 2009

International Journal of Epidemiology 2009;**38**:1137–1140
doi:10.1093/ije/dyp172

Population adiposity and climate change

Phil Edwards* **and Ian Roberts**

Accepted 3 March 2009

Background The increasing global prevalence of overweight and obesity has serious implications for the environment, as well as for health. We estimate the impact on greenhouse gas emissions of increases in the population distribution of body mass index (BMI).

Methods We estimated the food energy required to maintain basal metabolic rate in two hypothetical adult populations using the Schofield equations for males and females. Additional greenhouse gas emissions due to higher fuel energy use for transporting a heavier population were estimated.

Results Compared with a normal population distribution of BMI, a population with 40% obese requires 19% more food energy for its total energy expenditure. Greenhouse gas emissions from food production and car travel due to increases in adiposity in a population of 1 billion are estimated to be between 0.4 Giga tonnes (GT) and 1.0 GT of carbon dioxide equivalents per year.

Conclusions The maintenance of a healthy BMI has important environmental benefits in terms of lower greenhouse gas emissions.

Keywords Climate, greenhouse effect, body mass index, obesity, overweight, food, transportation

Introduction

World-wide, over 1 billion adults are overweight and around 300 million are obese.[1] The increasing global prevalence of overweight and obesity has serious implications for health, increasing the risk of type 2 diabetes, cardiovascular disease, stroke and some cancers.[1] Obesity is assessed using body mass index (BMI) $\geqslant 30\,kg/m^2$ and represents the upper tail of the population distribution of BMI. However, there is some evidence that the entire population distribution of BMI may be shifting upwards, increasing the risks of disease for the whole population and not only for the most overweight in the upper tail.[2]

The upward shift in the population distribution of BMI could also have important environmental consequences. Food production accounts for an estimated 20% of global greenhouse gas (GHG) emissions and food consumption is intimately linked to BMI.[3,4] Transport accounts for ~14% of emissions and population increases in BMI could impact importantly on transportation fuel energy use.[5]

In this article, we estimate the impact on GHG emissions of increases in the population distribution of BMI. We compare a 'normal' adult (30–59 years) population of 1 billion people with mean BMI of $24.5\,kg/m^2$ and 3.5% obese, with a corresponding 'overweight' population with mean BMI of $29.0\,kg/m^2$ and 40% obese. Our normal population BMI distribution reflects the UK situation in the 1970s and our overweight population BMI distribution reflects that predicted for the UK in 2010. We assume that half the population is male and that individuals have the same average height of 1.75 m for males and 1.60 m for females. These broad assumptions, which affect predicted energy expenditure, would be reasonable for populations in high-income countries.

Department of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, London, UK.

* Corresponding author. Room 186, NPHIRU, Department of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, Keppel Street, London WC1E 7HT, UK. E-mail: phil.edwards@lshtm.ac.uk

Food energy consumption and rising BMI

Energy expenditure studies in free living adults, using the doubly labelled water technique, show that total energy expenditure increases with increasing BMI.[6] Basal metabolic rate (BMR) increases mainly due to the increase in metabolically active lean tissue that accompanies fat gain. Activity energy expenditure also increases due to the greater energy cost of moving a heavier body.[6] Since it can be assumed that energy expenditure is approximately balanced by energy intake, it follows that total food energy consumption increases as BMI increases. We estimated the food energy required to maintain BMR in our hypothetical adult populations using the Schofield equations for males and females.[7] The equations used were $11.5\,w + 873$ kcal per day for males and $8.3\,w + 846$ kcal per day for females (w = weight in kilogrammes).

To estimate activity energy expenditure, we assumed that the normal and overweight populations have the same pattern of daily activities comprising 7 h sleeping, 7 h of office work, 4 h of light home activities, 4 h sitting, 1 h standing, 30 min of driving and 30 min of walking at 5 km/h. Estimates of the ratio of the metabolic rate for each of these activities to a resting metabolic rate of 1 kcal/kg/h (1 MET) were applied to the individuals in each population, to estimate their daily activity energy expenditures.[8] The energy costs used were: sleeping (1 MET), office work (2 METs), light home activities (1.5 METs), sitting (1.2 METs), standing (1.2 METs), driving (2 METs) and walking (3.5 METs).

On the basis of these assumptions, and using a conversion of 1 kcal = 4.184 kJ, we estimate that the normal population requires an average of 6.49 megajoules (MJ) per person per day to maintain BMR, and a further 3.81 MJ per person per day for activities of daily living, and that the overweight population requires an average of 7.05 MJ per person per day to maintain BMR, and 5.25 MJ per person per day for activities of daily living. Compared with the normal population, the overweight population requires 19% more food energy for its total energy expenditure.

In 2000, the total global emission of GHGs was ~42 Giga tonnes (GT) of carbon dioxide equivalents, for a world population of ~6 billion.[9] One billion people might therefore be considered responsible for ~7 GT of carbon dioxide equivalents per year. Since food production by the agricultural sector accounts for ~20% of total GHG emissions, food production might account for ~1.4 GT (20%) of the 7 GT per year for the normal population. A 19% increase in food consumption by an overweight population would therefore result in an increase in GHG emissions to 1.67 GT per year—an absolute increase of 0.27 GT per year.

Transport energy consumption and rising BMI

Compared with the normal population, we would expect the overweight population to have higher transportation fuel energy use because of the additional fuel energy needed to transport heavier people. The proportionate increase in fuel energy use (and thus GHG emissions) due to a person's weight per kilometre is estimated as car weight plus half the mass of the person, divided by car weight (Leonard Evans, personal communication). To estimate the GHG emissions due to car travel by each population, we assumed that all individuals with BMI < 30 kg/m^2 use an average small car (e.g. Ford Fiesta) and that individuals with BMI $\geqslant 30$ kg/m^2 use a car with more internal space (e.g. Ford Galaxy). The Ford Fiesta weighs 1530 kg and produces 147 gCO_2 per km, whereas the Ford Galaxy weighs 2415 kg and produces 197 gCO_2 per km. We assumed that the daily 30 min of driving is at an average speed of 45 km/h. Since transport accounts for ~14% of global GHG emissions, our hypothetical population of 1 billion would be responsible for 0.98 GT of the 7 GT carbon dioxide equivalents per year. Our model estimates that the normal population would produce 1.25 GT per year, and that the additional fuel energy used by the overweight population would increase GHG emissions by 0.15 GT per year.

Newton's first law of motion expresses the idea that any mass will remain at rest unless acted upon by a force. The reluctance of mass to start moving is known as inertia. Energy is required in order to overcome inertia and the greater the mass the more energy is required. Because these basic physical laws also apply to human bodies, total body weight is a key determinant of the energy cost of walking. The increase in energy expenditure with increasing body weight should prevent further weight gain in a negative feedback loop but with rising BMI people are likely to move less, particularly those who are substantially overweight.[10] Even when walking at their preferred walking speeds, heavier people are making a greater relative aerobic effort. Walking is an effort for heavier people and therefore some reluctance to walk would not be surprising.[10] As a mode of transport, walking provides access to goods and services and since people are likely to have the same demand for access irrespective of body weight, one might reasonably expect that heavier people would replace walking trips with motorized transport.

To estimate the modal shift from walking to car travel for the overweight population, we have assumed a daily distance walked of 2.5 km and a daily walking energy budget of 123 kcal (515 kJ) per day.[11] This distance is that covered by the daily walking of 30 min at 5 km/h, and the energy is the average amount required for a person with a BMI of 24.9 kg/m^2 to walk this distance. Each individual with a

BMI > 24.9 kg/m^2 requires more energy to walk 2.5 km than is available in the walking energy budget, and so switches part of this journey to motorized travel. Since energy use increases with increasing body mass, a larger proportion of the 2.5 km is travelled by motorized transport as BMI increases. For the normal population, the modal shift to car travel for the upper tail of the BMI distribution accounts for 0.005 GT of GHG emissions per year. In the overweight population, a larger proportion of the population shifts walking to car travel, accounting for 0.024 GT of GHG emissions per year. The total additional fuel energy used by the overweight population would therefore increase GHG emissions by 0.17 GT per year.

Aviation is a key component of transportation emissions. If we assume that 5% of the population take one short-haul flight totalling 3000 km each year, this is equivalent to 150 billion passenger kilometres per year. Jet fuel required to transport 6630 kg for 1 mile by air is ~1 gallon.[12] The difference in the average weight of the overweight and normal populations is 13.4 kg, and so the additional jet fuel required to transport the additional weight would therefore be ~187 million gallons per year, resulting in a further 2 MT of CO_2 emissions.

The BMI distributions for normal and overweight populations are shown in Figure 1. The daily energy requirements and corresponding GHG emissions from food production are summarized in Table 1.

Our estimates of GHG emissions due to population adiposity assume equal per capita emissions. It is likely, however, that a disproportionate amount of emissions are produced by populations in high-income countries, where obesity is also most prevalent. The population we describe might therefore be considered to be responsible for a third, or possibly half of total global GHG emissions. If we assume that our normal population contributes a third of total annual emissions, the 19% increase in food consumption by the overweight would lead to an increase of 0.54 GT carbon dioxide equivalents per year. If half of global emissions were produced by our overweight population, the emissions due to increased adiposity would be 0.81 GT per year. When we include the additional GHG emissions due to car travel it is likely that increased adiposity is responsible for between 0.44 GT and 0.98 GT carbon dioxide equivalents per year.

Discussion

We argue that increased population adiposity, because of its contribution to climate change from additional food and transport GHG emissions, should be recognized as an environmental problem.

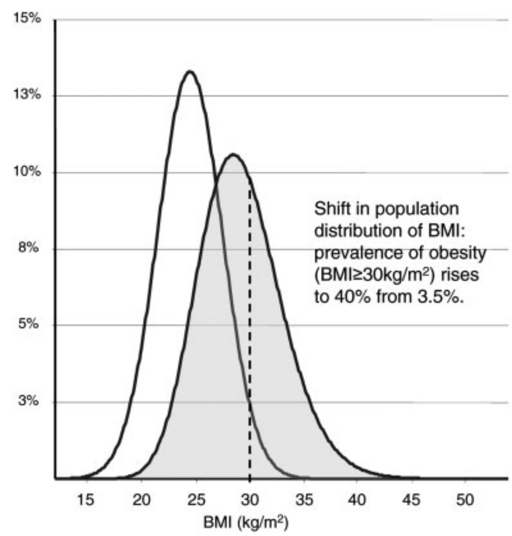

Figure 1 BMI distributions in a normal and an overweight population

Table 1 GHG emissions of a normal and an overweight population

Adults (age 30–59 years)	Normal	Overweight	Δ	θ
BMI (Mean)	24.5	29.0		
BMI (SD)	3.00	3.85		
Underweight (BMI < 18.5) (%)	2.2	0.0		
Obese (BMI ⩾ 30) (%)	3.5	40.3		
Morbidly obese (BMI ⩾ 40) (%)	0.0	0.7		
Energy for BMR (MJ/day)	6.490	7.051	0.561	1.086
Total energy expenditure (MJ/day)	10.302	12.300	1.997	1.194
GHG due to food production (GT/y)	1.400	1.671	0.271	
GHG due to oxidizing food (MT/y)	0.506	0.583	0.077	
GHG due to car travel (GT/y)	1.248	1.403	0.154	1.124
GHG due to modal shift to car travel (GT/y)	0.005	0.024	0.019	4.622
Total GHG due to car travel (GT/y)	1.254	1.427	0.173	1.138
GHG due to air travel (MT/y)	10.51	12.55	2.038	1.194

Δ, Absolute increase due to adiposity; θ, Relative increase due to adiposity.

We used a normal (Gaussian) distribution to model the population BMI distribution and a log-normal distribution to model the skewed distribution reflecting a higher prevalence of obesity and morbid obesity in the 'overweight' population.[13] These are theoretical statistical probability distributions, which may not be expected to describe perfectly the shapes of the population distributions of BMI observed in high-income countries. However, bearing in mind that our normal population approximates the UK situation in the 1970s, and our overweight population the situation predicted for the UK in 2010, we consider these statistical distributions sufficient for our purposes of providing estimates of the likely impact on GHG emissions of increasing population adiposity.

In our model, we have assumed that the distributions of activities of daily living are identical in the normal and overweight populations. If the average daily amount of physical activity in the overweight population was lower than that in the normal population (e.g. more time spent watching television instead of light home activities), then we would have over-estimated average energy expenditure in the overweight population. When we assume plausible lower levels of daily activities in the overweight population (30 min light home activities instead of 4 h, 8 h of sitting instead of 4 h and 30 min of standing instead of 1 h), the average activity energy expenditure falls from 5.25 to 4.89 MJ per person per day. However, compared with the normal population, the overweight population would still require 16% more food energy for its total energy expenditure.

Because some studies show that up to one-third of the food that is purchased is wasted, higher food consumption is likely to result in more food waste. The majority of waste food is either landfilled, where organic waste releases the powerful greenhouse gas methane when it decomposes, or it is incinerated producing CO_2. Although wasted food increases the GHG impact of the overweight population, we have not included these emissions in our estimates.

We have estimated the additional GHG emissions due to increases in population adiposity. In doing so, we have made a number of assumptions all of which can be questioned. Nevertheless, the assertion that increasing population adiposity will result in an increase in GHG emissions is justifiable and provides further evidence of the link between human health and climate change mitigation.

Conflict of interest: None declared.

KEY MESSAGES

- In many countries, the population distribution of BMI is shifting upwards with higher average BMIs and more overweight and obesity.
- Compared with a 'normal' population distribution of BMI with ~3% obese, a population with 40% obese requires 19% more food energy for its total energy expenditure.
- GHG emissions from food production and car travel due to increases in adiposity in a population of 1 billion are estimated to be between 0.4 and 1.0 GT of carbon dioxide equivalents per year.
- The maintenance of a healthy BMI has important environmental benefits in terms of lower GHG emissions.

References

1. http://www.who.int/dietphysicalactivity/publications/facts/obesity/en/ (23 March 2009, date last accessed).
2. Bell AC, Ge K, Popkin BM. Weight gain and its predictors in Chinese adults. *Int J Obes Relat Metab Disord* 2001;**25:**1079–86.
3. McMichael AJ, Powles JW, Butler CD, Uauy R. Food, livestock production, energy, climate change, and health. *Lancet* 2007;**370:**1253–63.
4. Roberts I. Comment and analysis: say no to global guzzling. *New Sci* 2007;**309:**21.
5. Woodcock J, Banister D, Edwards P, Prentice AM, Roberts I. Energy and transport. *Lancet* 2007;**370:**1078–88.
6. Prentice AM, Black AE, Coward WA, Cole TJ. Energy expenditure in overweight and obese adults in affluent societies: an analysis of 319 doubly-labelled water measurements. *Eur J Clin Nutr* 1996;**50:**93–97.
7. Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* 1985;**39 (Suppl 1):**5–41.
8. Ainsworth BE, Haskell WL, Whitt MC *et al*. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;**32 (Suppl 9):** S498–516.
9. Stern N. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press, 2007.
10. Swinburn B, Egger G. The runaway weight gain train: too many accelerators, not enough brakes. *Br Med J* 2004;**329:**736–39.
11. Kölbl R, Helbing D. Energy laws in human travel behaviour. *New J Phys* 2003;**5:**1–12.
12. Dannenberg A, Burton D, Jackson R. Economic and environmental costs of obesity. The impact on airlines. *Am J Prev Med* 2004;**27:**264.
13. Penman AD, Johnson WD. The changing shape of the body mass index distribution curve in the population: implications for public health policy to reduce the prevalence of adult obesity. *Prev Chronic Dis* 2006;**3:**A74.