PURGE Public health impacts in URban environments of Greenhouse gas Emissions reduction strategies

Project acronym:	**PURGE**
Project full title:	**Public health impacts in urban environments of greenhouse gas emissions reduction strategies**
Grant agreement no:	**265325**

FINAL PUBLISHABLE SUMMARY REPORT

September 2014

SEVENTH FRAMEWORK PROGRAMME

Executive summary

Global progress to date in reducing greenhouse gas (GHG) emissions has fallen far short of the action required to achieve a low risk of disruptive climate change over this century. However, there is growing evidence that the transition to the low carbon economy has the potential for appreciable ancillary benefits to human health. Such health impacts were the focus of the FP7 PURGE project (Public health impacts in URban environments of greenhouse gas emissions reduction strategies), which developed new evidence through a combination of model-based evaluations of specific GHG reduction policies in various sectors and settings, and economic analyses of consumer behaviour with respect to energy efficiency. Eight cities were chosen across four countries to act as 'case studies' for the modelling work: London and Milton Keynes (UK), Belgrade and Nis (Serbia), Beijing and Wuxi (China), and Delhi and Vishakhapatnam (India). The cities were chosen to represent both established and growing urban centres in each country. Key findings include:

- In the transport sector, measures which increase active travel (walking/cycling) alongside improved vehicle emission standards could greatly reduce CO_2 emissions with appreciable reductions in mortality and morbidity. These benefits would be primarily for cardiovascular health and would greatly outweigh the increased risk of road traffic injuries;
- Interventions which increase the energy efficiency of housing can lead to substantial benefits for health, mainly through improved winter internal temperatures and protection against outdoor air pollution. However, reducing uncontrolled ventilation in dwellings may have appreciable adverse impacts on health through increased exposure to indoor-generated pollutants;
- Relatively minor changes to dietary patterns which achieve current nutritional guidelines (and hence help improve health) will also reduce GHG emissions. Additional health benefits can be achieved by dietary modifications which reduce emissions further, although drastic GHG reductions may require large and unpalatable modification of current diets;
- Future transition pathways for electricity generation that rely on nuclear and renewable energy sources have the lowest cumulative CO_2 emissions. However, more rapid implementation of nuclear is critical to its effectiveness in reducing emissions;
- Data from consumer surveys in Italy on energy efficiency suggest that householders prefer policies that promote renewables over policies that target energy efficiency and prefer incentive-based policies over policies that impose taxes. Economic analyses also suggest there can be appreciable rebound effects from energy efficiency investments in the residential sector, which partly offset the expected gains in energy savings, and may sometimes be so great as to increase energy use (a 'backfire' effect).

The findings of PURGE provide an additional rationale for increasing the pace of action to mitigate the harmful effects of climate change. The tools developed in the project will support the formulation of policies in different sectors of society which enable the major transformations required in ways which protect, and ideally improve, population health.

Summary description of the project context and the main objectives

The PURGE project was aimed at understanding the consequences for health of strategies to reduce the emissions of greenhouse gases (GHGs) in urban environments.

Over recent years there has been growing evidence and recognition that policies to reduce greenhouse-gas (GHG) emissions can have direct and potentially large effects on population health. They are often, but not universally, beneficial.

These ancillary effects for health (sometimes referred to as health 'co-benefits' if positive) arise from reduction of exposures to environmental pollutants (such as air pollution) and from the promotion of health-related behaviours (healthy diets, walking and cycling). They are additional to any impacts on health arising from the mitigation of climate change. They typically arise in the short term from well-understood changes to direct 'exposure pathways,' and are thus less uncertain than the potential distant effects of climate change mitigation. They are important because they can provide an additional rationale to pursue mitigation strategies, and demonstrate opportunities by which population health may be improved while pursuing environmental objectives.

The PURGE project aimed to add further evidence in this area by developing methods to quantify the positive and negative impacts on health and wellbeing of GHG reduction strategies in urban areas of Europe, China and India, so as to inform policy decisions in such areas as energy, housing/built environment, transport, and food.

The specific objectives may be summarized as follows:

• To define the critical policy choices for mitigation in selected settings in Europe, China and India, and the parameters within which those choices are constrained

• To delineate sets of specific interventions, tailored to local needs, which meet the demanding abatement trajectories at several future time points (2020, 2030, 2050)

• To quantify the changes in health-affecting 'exposures' and health behaviours that are likely to accompany those interventions and policies, and hence

• To quantify the health impacts (mortality and morbidity) associated with those policy choices

• To address important evidence gaps about the behaviour changes that are likely from selected mitigation measures, and about forms of economic influence on patterns of energy consumption

• To determine the costs and benefits to health of the mitigation measures examined from societal, household and health service perspectives

• To examine the implications of such evidence for policy decisions, in the context of uncertainty, taking account of both positive and negative potential impacts.

The project developed evidence using models for cities (four large established cities, and four smaller growing cities) and regions of Europe and Asia with models of change relating to one or more of the four sectors noted above: transport, electricity generation, housing and food. In developing the modelling methods and tools to carry out these assessments the project contributed numerous methodological insights and developments that will aid further research in this field. Its economic components addressed questions about achieving investments and behaviour change, specifically in relation to energy efficiency.

Its evidence adds further insight into the forms of greenhouse gas reduction strategy most likely to be beneficial to health, and the potentially adverse unintended consequences of mitigation policies so they may be better informed to protect and promote health.

Main S & T results/foregrounds

The PURGE project developed methods and evidence relating to the health impacts of possible greenhouse gas (GHG) reduction strategies in urban environments in Europe and Asia. It did so through models that attempted to quantify the effect of direct pathways influencing health, such as those relating to exposure to environmental pollutants (e.g. toxic air pollutants) and changes in health-related behaviours (e.g. diet, physical activity). It did not consider health effects arising through any contributions to the mitigation of future climate change. Negative effects for health and unintended adverse consequences were quantified as well as the positive.

The models focused on interventions in housing, food and agriculture, transport, and electricity generation, and examined their impact on health in eight 'case study' cities in four countries: London and Milton Keynes in the UK, Belgrade and Nis in Serbia, Beijing and Wuxi in China, and Delhi and Vishakhapatnam in India. Models of change relating to one or more of the four target sectors were developed for each city. The primary focus was on interventions of that could make substantial contributions to the fulfilment of needed GHG emissions reduction targets appropriate for each setting. However, no region, nation or city examined in this project has both an adequate set of mitigation targets and convincingly demonstrated that it is moving with sufficient pace to achieve them. Emissions reduction scenarios were therefore somewhat hypothetical, but designed to illustrate the nature and approximate magnitude of health effects that could be expected if necessarily ambitious low carbon policies were widely applied.

The impact of GHG reduction measures on health

Full details of the model methods and results developed to test scenarios in each setting are described in the project reports for each work package. Here we summarize the headline results and selected other results of most relevance to policy. They are presented sector by sector.

Transport

- In line with previous research, models based on travel data for London demonstrated potentially substantial benefits for cardiovascular health and cancer reduction of interventions which increase active travel (walking and cycling) and reduce use of motorized vehicles. Overall, such benefits greatly outweigh the potential disadvantage of increased risk of road traffic injury. An analysis of existing travel patterns suggested that realistic mode shifts towards increased active travel may largely be limited to short journeys of up to around 1 km for walking and up to around 5 km for cycling. Though potentially important for public health, such shifts in modes of travel would have relatively modest impact on the totality of transport-related greenhouse gas emissions for London, and would therefore need to be combined with measures to switch to renewable energy sources.
- In India, models were developed for the two target cities (Delhi and Vishakhapatnam), in both of which a little over 50% of all trips are currently by non-motorized modes (walking, cycling and cycle rickshaw) suggesting limited potential to increase non-motorized shares in future. Moreover, about 75% of the car and motorcycle fleet is less than 5 years old. Nonetheless, as the share of cycling is low (<10%), there is theoretical potential to shift some car and motorcycle trips to this mode in the future, and there is also some potential with more efficient public transport systems to shift a proportion of car trips to bus and metro, though the high incidence of road traffic injuries (10-15 fatalities per 100,000 persons per year) will have to be reduced to make non-motorized modes more acceptable to the population. For both cities

plausible measures could reduce CO_2 emissions due to traffic by 0.8-1.0 tonnes per capita per year by 2030 and achieve appreciable estimated reductions in fatalities and morbidity -- primarily due to the increase in physical activity, some changes in road traffic fatalities and the effects of reduction in pollution.

Housing

- Studies in the UK (London and Milton Keynes) and elsewhere suggest that housing energy efficiency interventions also have the potential for appreciable net benefits to health. However, when designing for low energy use and good health there are frequently important trade-offs. This is exemplified by the range of effects that may arise from changes in ventilation. An increase in the air-tightness of dwellings to help reduce energy demand will tend to increase the concentrations of pollutants derived from indoor sources, although protecting against the ingress of pollution from outside. Thus, particular risks may arise from pollutants generated inside the home such as radon, second-hand tobacco smoke, particle pollution from indoor sources, mould growth and volatile organic compounds. The optimal level of ventilation and other dwelling characteristics that maximize health and environmental goals vary with local circumstances. For the UK, it appears that healthy, low-carbon pathways may be best achieved by combination of decarbonizing the energy sources (electricity grid) in conjunction with a partial retrofit with simple energy efficiency measures to the building envelope rather than relying dominantly on extensive and costly retrofit measures to improve energy efficiency.
- In Delhi, there is also potential for substantial reduction in both CO_2 emissions and health exposures to most airborne pollutants. A 50% reduction in CO_2 emissions would be achievable through simple, inexpensive housing interventions and some decarbonization of the power supply. However, given high outdoor particle levels, even with reductions in indoor sources and the use of extraction fans for cooking, the daily mean of $PM_{2.5}$ for a cook would typically exceed $75\mu g.m^{-3}$ – emphasising the need for more ambitious action to reduce ambient particle concentrations as well as minimizing exposure from indoor sources.
- In Beijing, depending on type of dwelling, the application of retrofit energy efficiency measures could achieve annual energy savings of up to 50%. High levels of exposure to indoor particles are common, however, with substantial contributions from cooking activity. The most critical dwellings are those with no mechanical ventilation. The median indoor level of $PM_{2.5}$ in such dwellings is up to six times greater than the already very high ambient concentrations. Protection against the ingress of high outdoor particle pollutant levels combined with extraction of those generated inside the home could make appreciable contributions to improving health (e.g. with filtered mechanical ventilation systems). Our analyses suggest that it is possible to reduce indoor PM concentrations by an order of magnitude by 2050 by mandatory use of high-capacity kitchen exhaust fans compliant with the Chinese Residence design standard GB50096-1999.
- In Belgrade and Nis (Serbia), business-as-usual actions are projected to result in only modest reductions in energy use and consequently greenhouse gas emissions (21% for the Belgrade domestic stock, 27% for Nis by 2050 compared with 2006). Plans for more demanding and expensive thermal retrofitting measures could achieve theoretical reductions of 50-54% by 2050 compared with 2006 for both cities, with accompanying reductions in $PM_{2.5}$ especially in single family homes.

Food and agriculture

- Greenhouse gas emissions associated with food and agriculture make a substantial contribution to national GHG emissions totals and modifications to dietary patterns could help achieve both health and climate change mitigation goals. Modifying the UK diet to comply with WHO dietary recommendations (even without specifying a GHG reduction target) would achieve around a 17% reduction in GHG emissions, while saving almost 7 million years of life lost prematurely in the UK over the next 30 years and increasing average life expectancy by over 8 months, primarily due to reduced coronary heart disease. Larger reductions in GHGs could be achieved by reducing consumption of animal products and soft drinks and increasing consumption of fruit, vegetables and cereals. These changes would also be accompanied by further improvements in population health. However, to achieve more than a 40% reduction in GHGs would require radical, and probably unacceptable, changes to current diets. Moreover, as there are more and more extreme departures from the current dietary pattern to meet stringent GHG reduction targets, the improvements in health become more marginal and in some cases begin to reverse from those estimated to occur at slightly lower levels of GHG reduction.
- The current diet in Spain is also far from healthy for both men and women at all ages. The intake of proteins, fats, saturated fats, cholesterol, free sugars and salt is too high, while the intake of carbohydrates and fibre is too low. Only the consumption of fruits and vegetables is broadly in line with health guidelines. The average diet of males between 18-65 years contributes 246 kg of CO_2e a month, while for the average women the emissions are about 201 kg CO_2e. Of the total diet-related emissions, 27-32% comes from the consumption of meat, 17-20% from dairy, and 17-20% from fruits and vegetables. A shift to a healthier diet would bring an incidental 13% reduction in CO_2 emissions, but optimizing it to meet nutritional and stringent CO_2e reduction goals would require very large increases in consumption of commodities such as rice, low fat spreads and unprocessed potatoes, while reducing the consumption of meat, milk and milk products, and sugary products by around 40 to 60%. In a model which assumes no cap on the subsidies on food the analyses suggest there would be no increase in individual spending on food, and the combination of the taxes and subsidies would result in an annual net tax receipt by the government on the order of €16 billion. While the practical upper limit of achievable change in the UK diet seems to correspond to a 40% reduction, for Spain the limit is closer to half the UK value, or 22%. For this reduction, the avoided cost of CO_2 would be 95 €/t, which is quite high.
- The current average diet in China is closer to WHO recommendations than most European diets, but the trend is for increased sugar and animal products which will have negative consequences for both health and GHG emissions. Measures to halt and reverse this trend will therefore be required to meet longer term health and environmental objectives.

Electricity generation

- In China, emissions of particles and other pollutants arising from coal-based generation of electricity are substantially higher than in Europe in both absolute terms and per terawatt hour of generation. At the country level, the total external cost of electricity generation (in terms of monetized adverse health impacts) lies in the range 65 to 530 B$ at 2010 prices, with a mean estimate of 322 B$. The latter mean cost estimate represents more than 5% of China's GDP in 2009. Per kWh of electricity, this is a cost of 5.71 US ¢ (2010 prices), a value 50% greater than the price of coal consumption per kWh (0.22 Yuan per kWh), and more than double the damage cost of coal-based generation in Europe (2.4 US ¢ per kWh). Just 13% of installations contribute 50% of the overall damage cost.

- These figures suggest the potential for appreciable gains to health from reduced dependence on coal and other fossil fuel-based generation which in part could offset the costs of low carbon policies. Using the marginal damage costs (€/kg emission) to calculate the health impacts and damage costs of future emission scenarios suggest that the use of a 'Carbon Cap' would result in the lowest future damage costs.
- GCAM (Global Change Assessment Model) models of electricity production to 2050 were explored to examine the effect of four climate policies, selected to reflect different levels of carbon price, differentiated by region (rich vs. poor countries). The high carbon tax scenario assumes a higher price between 2010 and 2050 than the low tax case (130 vs. 40 $2005 per tCO2 by 2050). The low carbon cap scenario reduces global emissions 40% below 2005 levels in 2050, whereas the high abatement case achieves 60% reduction against 2005, or 50% less compared to 1990. Delaying interventions will result in higher carbon taxes in future years, which will be necessary to offset the additional emissions that have occurred due to the initial delay.
- Without strong climate policies, fossil fuels will dominate future generation, with coal the fuel of choice in China and India. For Western Europe, natural gas provides about 30% of demand in 2050. With increasing carbon price, CCS accounts for about half of the electricity generation by the middle of the century, along with a strong presence of nuclear and renewables (notably solar in India). Electrification of the transportation sector accounts for about 10% of the final electricity demand in Western Europe. Industry accounts for at least 40% of the electricity demand, followed by commercial and residential end-users. Residential electricity use increases significantly in China and India due to rapid urbanization, but only marginally in Western Europe primarily due to fuel switching (e.g., gas to electricity for heating).
- Depending on assumptions of technology readiness (CCS) and social acceptability of energy options (nuclear), global and regional carbon emissions vary by a factor of two to three in 2050. Compared to 2005, carbon intensities of electricity production in 2050 are reduced by 55% in India, by 70% in China and in excess of 80% in Western Europe. The downward trend continues for the rest of century, with Western Europe reducing its emissions 95% against 2005 by 2100. Emission intensities of other pollutants, such as PM, NOx and SO_2, also decrease noticeably over time across all regions and scenarios.
- Cross technology gap costs decrease over time; this is especially the case for solar power generation. Fossil fuels become less competitive as carbon price increases. Costs curves do not take into account the full impact of environmental and health damage costs (externalities), other than the effects of CO2. Fuel prices, and technology development (backup storage) and deployment (nuclear power or CCS) assumptions have a strong impact on future electricity prices.
- Current generation bio-fuels can reduce fleet CO_2 emissions by between 10 and 17%. The lower figure applies to feedstocks that impact land use changes (LUC), such as rapeseed. Future bio-fuels based on cellulosic feedstocks and non-food crops (algae) are expected to have much lower lifecycle carbon emissions (half of current fuels), higher yield rates, and will compete less for croplands.
- All things being equal, future transition pathways that rely on nuclear and renewable energy sources have the lowest cumulative CO_2 emissions and some of the largest potential savings in terms of health impact. However, timely implementation of nuclear is critical to its effectiveness in limiting carbon emissions. Delaying nuclear construction by 10 years, for example, reduces cumulative CO_2 emissions in 2050 against 2010 levels to 36% vs. 41% savings without the delay. Aggressive behavioural modifying interventions over the same time period would yield equal or potentially higher saved carbon emissions, on top of greater benefits on local air quality and hence health benefits.

Changes in outdoor air pollution arising from mitigation strategies

- Models of the health impacts and costs of lifecycle emissions of PM, SO_2 and NO_x provide evidence on air pollution-related effects in the transport sector of modal shifts, changes in mobility technology, and active transport (i.e. walking/cycling). These suggest that behavioural changes (e.g. shifting to public transportation, walking instead of driving, driving EVs, purchasing more fuel efficient cars, etc.) are as effective in reducing overall damage costs as technology options, such as for example switching from fossil fuel-based generation to nuclear power, or relying on end of pipe fixes such as carbon capture and storage. More importantly, behavioural changes bring greater improvements in local air quality because displaced emissions are ground-level emissions, whereas stack emissions occur far away from where the traffic is located, and high up in the air, which lead to greater dilution and lower urban population exposure.
- In China, the emissions of air pollutants increase appreciably under business-as-usual (BAU) trajectories, with hotspots in southern Beijing, central Tianjin and north-eastern Hebei. However, under a climate mitigation (CMP) scenario, emissions of pollutants harmful to human health in Beijing decrease significantly, although emissions from surrounding regions remain similar to those in 2010. Compared with 2010, in Beijing under the BAU scenario, the NO_2, SO_2 and $PM_{2.5}$ average concentrations by will increase by 22-24%, 20-23%, 18-23% by 2015, and by 40-43%, 37-41%, 30-42% by 2020, while under the CMP scenario, the NO_2, SO_2 and $PM_{2.5}$ average concentration in Beijing will decrease by 0-8%, 0-8%, 4-9% by 2015, and by 4-24%, 6-24%, 14-26% by 2020. Without climate mitigation measures and improvements in emission control technologies, the air pollution problem in Beijing and its surrounding regions would deteriorate. Implementation of measures in the 12th Five-Year Plan, including a 17% cut in CO_2 intensity by 2015 on the national scale could prevent deterioration of air pollution, but would result in little improvement compared with 2010.
- Coal is the dominant energy source in Beijing and its surrounding region (megacity Tianjing and Hebei Province), and therefore responsible for severe air pollution in this region. Replacing coal with natural gas is proposed as one of the most important policy for air quality improvement. An integrated analysis based on GAINS-China and WRF-Chem was conducted to analyse the effectiveness of this policy.
- We found that using natural gas to replace coal in the residential sector will achieve the largest reduction in SO_2 and $PM_{2.5}$ concentrations in Beijing, Tianjin and Hebei province and hence the largest health benefits, while replacing coal with natural gas in the industrial sector will achieve the largest reduction in NOx concentration. There is no significant change of surface $PM_{2.5}$ concentration in scenarios focused on the power and industrial sectors compared with baseline, but actions targeted at the residential sector achieve the largest reduction in $PM_{2.5}$ concentrations across the Beijing-Tianjin and Hebei Province.
- In Delhi the estimated shares of $PM_{2.5}$ and CO emissions were 17% and 18% for vehicle exhaust, 16% and 31% for power plants, 15% and 12% for brick kilns, 14% and 15% for industries, and 12% and 14% for domestic, respectively. In Vishakhapatnam, the $PM_{2.5}$ shares are estimated at 39% for power plants, 29% transport, 14% manufacturing industries, and 8% domestic. Annual mortality due to overall particulate matter in 2011 are estimated to be 550 per million population per year in Delhi (165 due to transport) and 765 per million per year in Vishakhapatnam (275 due to transport). Switching of coal-powered electricity generation plants to natural gas in Delhi by 2030 could result in a reduction of 50 fatalities and 1062 disability-adjusted life-years (DALYs) per million per year. Adopting Euro5 fuel norms by 2020 for the transport sector could result in a saving of 128 lives and 2767 DALYs per million population in Delhi.

Achieving change: evidence on choices

- Evidence on the influence of economic factors in determining energy use and energy efficiency investments by households was examined in the Czech Republic, Italy, Spain and China. Use of price as a measure of demand management may indeed offer an effective method to influence energy consumption by households. Estimates of long-term 'price elasticity' of residential energy demand suggest that a 1% increase in price would result in about -1.0% change in gas consumption in Spain and in electricity consumption in China, and a -0.4% to -0.87% change for gas in Czech Rep, and for electricity demand in Spain, respectively. These estimates of price elasticities imply quite large 'direct rebound effects'. However, however, considering the methodology we have followed in these studies, these estimates provide an upper bound – rather conservative – estimate of the direct rebound effect.
- Specifically, the household survey on energy use conducted in Spain revealed that if the residential energy efficiency of electricity increased by 10%, an estimated energy savings of only 1.34% would be realized, whereas for the same improvement in gas efficiency there would be increase in the demand for heating and domestic hot water by 0.94% (backfire). The estimate of electricity price elasticity also implies a 'backfire effect' in China, meaning that the improvement in energy efficiency may result in greater, not less, consumption of energy. However, at least in the case of gas demand by Czechs and of electricity demand by Spanish, improvements in energy efficiency will save energy and hence lower GHG emissions.
- Despite large direct rebound effects, upgrades in dwelling energy efficiency may generate positive effects in terms of increasing the market value of dwellings and helping to reduce fuel poverty (almost 17% of Spanish households admitted to not having been warm enough during the winter that preceded the survey).
- In Italy, evidence from analysis of population surveys suggests that respondents prefer policies that promote renewables over policies that target energy efficiency and prefer incentive-based policies and disapprove of policies that impose taxes. Their willingness to pay is €130 per ton of CO_2 emissions avoided. However, in relation to home energy efficiency investments, around 78% of the beneficiaries of an Italian efficiency programme were found to be 'free-riding', meaning that they would have replaced their heating system even without financial assistance. In such circumstances, financial assistance of the programme may therefore lead to further spending and rebound effects. Such effects were found to be appreciable in all three countries where behaviour of residents was analysed.
- Both subsidies and taxes could persuade consumers to switch from a standard device to a more efficient one. Czech respondents would be more likely to purchase energy efficient domestic electric appliances (e.g. washing machines) if their price was lowered by a rebate rather than if less efficient machines were taxed. However, a tax on non-labelled appliances in Spain has been found to be more cost effective in reducing energy consumption, with typically lower policy costs and lower social welfare losses than subsidies. Rebates or subsidies can result in increased energy consumption, which is known as the rebound effect. A mixture of taxes and subsidies (so called Bonus-Malus approach) is a good compromise from both an economic and social point of view.
- Analysis of survey data for Spain suggests that, if the goal is to reduce electricity consumption, households should diversify the fuels they use for heating and hot water. If the goal is to reduce natural gas consumption, because of evidence of a backfire effect (where the rebound effect is larger than 100%), households should seek to improve the energy efficiency characteristics of their homes, but continue using natural gas as an energy source for heating and hot water.

- The large-scale “Green For Saving Program” to support thermal insulation of family houses in the Czech republic resulted in reduced energy consumption. For such investments, a 10% increase in energy efficiency reduces gas use by only about 6% (i.e. there is a rebound effect of about 40%).
- In China, high-income households show greater change in electricity consumption in response to a change in long-term electricity price. Hence, low income groups will bear a heavier burden of electricity spending and suffer greater welfare loss due to their inelastic demand if there is a simple policy of price-increases. The role of electricity as a life necessity is more obvious in low income groups in urban China and with their income growing they will increase electricity consumption. The policy implication of this study is that since price and income elasticities of electricity consumption differ greatly among different income groups, if an electricity tariff reform is implemented, then either directly subsidizing low-income families or rationally setting the price levels of different income groups can help to mitigate adverse redistributive (social) effects.
- Analysis of household-level data for 10 OECD countries shows that those who are motivated to save energy tend to take action on multiple fronts: e.g. through every-day actions (e.g. turning off lights) and investing in energy efficiency retrofits. The practical implication of this is that increasing the motivation of individuals to save energy is likely to affect all types of energy-saving behaviour. This study also shows that the promotion of energy-saving behaviour can be achieved by lowering the difficulties of taking energy-saving activities.
- The health benefits of a tax incentive program targeting electricity consumption of European domestic hot water systems has shown that the benefit in physical terms would amount to saving one life per million homes per year. The social cost benefit would be around 2 million euros per million homes per year. The theoretical limit, assuming full implementation across the housing sector, comes to 0.4 billion euros annually.

Some methodological issues

In addition to the substantive results relating to GHG reduction interventions in different sectors, the PURGE project helped to advance the principles and methods for quantifying the health consequences of such interventions and policies.

- The project entailed the development of modelling tools to assess the impact on health and CO_2e emissions of sector-specific interventions. Desirable features of such models were found to include the use of population-representative data from local surveys, the ability to compare a range of policy choices with costs and benefits calculable for different target groups, and the monetization of impacts on health and in different sectors. The estimation of targeted individual-level health impacts can provide important detail on the “winners” and “losers” of a given policy. A model for assessing the health impacts of housing-related energy efficiency interventions in England is currently being tested as a support tool by the Department of Energy and Climate Change in the UK.
- Methodological developments undertaken as part of the project also focused on the use of semi-analytical methods to quantify and propagate uncertainties in such modelling, and the use of multi-objective optimization (as an example of a multi-criteria decision analysis method) to compare alternative mitigation strategies across several competing objectives or criteria. These methodological refinements have potential importance for assessing complex policy choices, though further research is needed to understand how such evidence would be most effectively presented and used.

- In terms of attaching costs and economic values to the health consequences of GHG reduction policies, several studies have examined the social costs of pollution on health, in particular health expenditures (either paid by the local public health system or out-of-pocket expenses incurred by sick individuals), loss of productivity (valued in terms of labour productivity loss, or wage losses plus replacement costs for hiring temporary workers plus indirect costs from loss of business activity), and loss of welfare due to sickness-related inconveniences. For a given health endpoint, these costs vary between countries in relation to economic wealth, and social healthcare system characteristics. In Europe, costs across countries typically vary by a factor of 2 to 3, with differences reaching an order of magnitude between West and East Europe. Productivity loses are significant.
- Concerning values for mortality risk reduction, the value of statistical life (VSL) for adults lies in the rage of €1.2 and €6 million in Europe. A meta-analysis carried for the OECD by Navrud and Lindhjem (2011) suggests a 'central' value of €3.6 million. For children, for whom a child risk premium multiplier of 1.5 appears appropriate, the VSL is therefore estimated to be between €1.8 and 9 million, with a central figure of €5.4 million. For economic valuation of cancers, the value of a life year (VOLY) is needed (€90,000), from which the cost of cancer death is obtained by multiplying the VOLY by the loss of life expectancy of the specific cancer in question. The cost of illness and productivity loss may be added to this. The equivalent cost of the Quality Adjusted Life Year (QALY) in Europe is estimated to have a value of around €64,000 (40 to 200 k€).
- Health costs in China and India (after adjustment for differences in GDP purchasing price parity per capita and income elasticity), are considerably lower than in Europe. As an example, the social cost of an adult statistical life (VSL) is 1/3rd of the European value in China and 1/8th in India. The QALY follows the same trend as the VSL. Compared to Europe, morbidity costs are between 16%-47% (China) and 8%-16% (India) lower for asthma and anxiety health end-points. These differences have evident implications for the comparison of policy choices across settings.
- As a further resource, a database has been compiled of the characteristics of selected Asian and European cities aimed at providing substrate for the assessment of potential greenhouse mitigation strategies with co-benefits for public health. Cities can be clustered with respect to a range of characteristics, and it may be particularly instructive to compare and contrast the policies and operational characteristics of cities of similar domain. Health impacts of different urban activities can be calculated if adequate data are available relevant to those specific activities. Health impacts due to transportation require detailed information on vehicles in use and their emission characteristics, modal shares of trips and trip lengths by mode, road traffic accident statistics including details of victim type, and dose response relationships for different inputs. For most of the cities included in our sample very few of the needed data are available in the public domain.

Summary

The PURGE project has sought and found evidence that measures to support the transition to a low carbon economy have the potential for appreciable benefits to population health particularly in urban environments – an observation that should give added impetus for the acceleration of policies to reduce greenhouse gas emissions. The opportunities and optimal solutions for interventions in different sectors vary from setting to setting. In general, the potential co-benefits for health of GHG reduction policies are greater in India and China than for European populations largely because of the greater exposure to air pollutants. However, European populations have diets which are both less healthy and carry relatively high CO_2e emissions, and there appears to be greater scope for environment and health gains from relatively modest adjustment to current dietary patterns. European populations are also relatively physically inactive, and sustainable transport policies which promote active travel may also entail correspondingly large benefits for public health. Action in both Europe and Asia will be vital to meet GHG abatement targets to limit the risk of disruptive climate change. The use of tools to assess the positive and negative impacts on health of such actions could help ensure policies maximize the opportunities for promoting health while minimizing the risk of adverse unintended consequences.

Potential impact (including the socio-economic impact and the wider societal implications of the project) and the main dissemination activities

The PURGE project has developed evidence on the health impacts of greenhouse gas reduction strategies in transport, electricity generation, housing and food and agriculture in urban environments of Europe and Asia. Its findings:

(1) Extend the existing evidence on the health impacts associated with GHG reduction strategies. To date, health impacts have received comparatively limited attention in debates about the cost-benefit of 'decarbonization' by comparison with, say, economic considerations. For many mitigation strategies, the net consequences for health are positive, and so add to the rationale for an accelerated transition to low carbon (low GHG) economies, perhaps by helping to off-set some of the perceived economic costs.

(2) Provide evidence on the types of GHG reduction strategy within each sector that are likely to have the greatest health dividend.

(3) Yield more detailed evidence on both the positive and negative consequences for health of such strategies, so that policies and regulation may be better tailored to ensure opportunities for promoting health are maximized and protective steps can be taken to avoid unintended adverse effects for health.

Such evidence will be useful at various levels of policy:

-- for international negotiations because of its bearing on the argument for wider (health-related) benefits of pursuing GHG abatement;

-- at European and national levels to help guide policies that can capitalize on the opportunities for improving public health through GHG reduction; and

-- within individual sectors, by providing evidence that can help inform regulation and guidance (for example, the setting of building standards) to protect and improve health.

Health benefits are not automatic of all low carbon policies, but the evidence of the models developed through PURGE support previous work which suggests there is often substantial *potential* for health benefit *if* policies are appropriately developed. Major and transformative changes are needed in all sectors of the economy and in all countries to meet global GHG emissions reduction targets. This presents an enormous challenge but also a unique opportunity to re-shape economic and social development to support a healthy and productive population without compromising environmental integrity at a global level.

<u>Societal impact</u>

The evidence from PURGE and other recent scientific research supports an important principle, namely that actions needed to achieve global environmental goals in relation to climate change can also help promote population health. The examples are numerous. Most strategies for sustainable transport entail substitution of petrol and other fossil fuels with ones that entail lower emissions of toxic pollutants to the local urban environment. They could also entail increases in active travel and reduced reliance on motor vehicle transportation, which would have benefits to health through increased physical activity. Power generation which is based on renewable or nuclear technology entails lower emissions of both CO_2 and toxic pollutants. Housing which is energy efficient can improve protection against winter cold and outdoor pollutants. And diets which entail lower greenhouse gas emissions are generally healthier diets low in meat and dairy products.

Most governments and administrations are reluctant to implement transformative policies to bring about the needed rapid reduction in greenhouse gas emissions. Many factors contribute to that reluctance, but among them is an argument of potential economic cost and disadvantage, which is seen as particularly important in the context of the recent financial crisis. Another is the perceived lack of appetite for major and potentially expensive policy initiatives to tackle a problem that is still viewed as low priority by the majority of the electorate. But evidence that such policies may be good for health while also improving quality of life provides an important additional rationale for accelerated action. Accounting for such benefits may also help to offset the costs of mitigation actions. Such considerations, along with the advantages of energy security, are important elements in current debates about the direction and ambitions of public policy. Collective action to mitigate climate change is one of the most important challenges for the 21st century, and evidence on the likely consequences and opportunities for health is a vital ingredient in the formulation of policies to address it.

The research evidence on health is important also in helping to inform more specific decisions about *how* policy should be developed. The modelling undertaken in this project was clear in showing that there are important areas in which the consequences of GHG reduction strategies could be negative for health. The examples include the road injury risks of policies that promote active travel without adequate safeguards of pedestrians and cyclists, possible poorer indoor air quality with insufficient ventilation of energy efficient dwellings, and the affordability of winter heating for poorer families in circumstances where unit costs of energy are increased to pay for the switch to renewable sources. These are consequences that can often be predicted and better understood through the use of detailed health models.

By helping to show the consequences for health of different GHG reduction strategies, the findings of PURGE and other research in this field could help contribute to decisions that help promote healthy, sustainable development of societies around the world: they will help to ensure that impacts on health are better understood and more visible to consider alongside economic and other factors. Health is an important facet of sustainable development and has evident bearing on equity – both within current society and across generations. The evidence from PURGE will therefore also contribute to understanding how health inequities and inequalities can be addressed through pursuit of environmental objectives. It adds further evidence on the benefits for health of GHG reduction strategies in different countries (specifically in the current context of investments in Europe, China and India) which is relevant to consideration of technology transfers, for example. But the primary message for policy is that there are important opportunities for health in almost all strategies aimed at reducing the emissions of greenhouse gases in urban environments.

Dissemination activities

Dissemination of the study findings has been to both scientific and policy audiences through a range of mechanisms. These include:

- Two 'launch' events, one in Asia and one in Europe with audiences of selected invitees. The first was held in Beijing on 13 June 2014, hosted by project partner Arup, the second in London on 23 July 2014, hosted by project coordinator London School of Hygiene & Tropical Medicine. These were attended by a wide range of stakeholders from different backgrounds and geographical locations. Among them were representatives of: the Asian Development Bank, Asia-Pacific Finance and Development Center, British Embassy Beijing (1st Secretary Low Carbon Growth), Department of Resource and Environment, China National Institute of Standardization, Chinese Academy of Sciences, Chinese Academy for Environmental Planning, Energy Foundation China, Europe-China Eco Cities Project, Department of Energy and Climate Change, UK, London Health & Housing Network, UK, The Climate Change Committee, UK, London Borough of Islington, UK, Serbian Ministry of Energy, State Environmental Fund, Czech Republic, Tsinghua University, Nanjing University, Peking University, UK Health Forum, WWF China.
- Publication of academic papers in the peer-reviewed literature. To date there have been 24 peer-reviewed papers published, with 15 further papers in submission or preparation. Papers have been made openly available as soon as possible after publication through institutional repositories. Many articles were also published in conference proceedings and as book chapters.
- Presentations at numerous scientific and policy-focused meetings. Presentations based on project work were made by partners at many well-attended scientific end public events worldwide. The comprehensive list of dissemination activities contains more than 130 events where partners have presented and discussed project work. This includes wide dissemination in the Asia Pacific region, Europe and North America, for example at: 2014 International Society for Environmental Epidemiology annual conference, Washington, USA; IARU Sustainability Science Congress 2014 – Global Challenges: achieving sustainability, Copenhagen, Denmark; ENRIC 2014: Natural Resources International Conference, Bangkok, Thailand; AGU Fall Meeting, San Francisco, USA (with nearly 24,000 attendees, the largest Earth and space science meeting in the world); the Earth League expert workshop, Santa Fe, New Mexico, USA; the Healthy Polis network annual conference, Manchester, UK.
- Successful stakeholder workshops, with strong participation of policy representatives from both national and regional level (including senior representatives in Serbia (one of the case study countries), and the UK, for example).
- Development of a *Guide to study findings for policy makers* which is being disseminated to a wide range of relevant stakeholders in both the scientific and policy area, via established networks as well as new contacts fostered during the project
- A study website containing a summary of the project and its outputs: http://purge.lshtm.ac.uk. This is hosted internally on the coordinator's server, and will remain active beyond the end date of the project, and be maintained and updated with further dissemination activities, especially scientific and other publications.
- Circulation of specific reports and other outputs to relevant targeted groups and agencies as appropriate. Among others, these target groups include the World Health Organization, government agencies (e.g. the UK Department of Energy and Climate Change), the European Science Foundation and others.

Public website address and relevant contact details

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