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SPECIAL ISSUE

Tools for developing adaptation policy to protect human health

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Abstract Anthropogenic climate change is likely to add significant pressure to the determinants of public health, and to current health and social protection measures in high, middle and low income countries. Adaptation strategies within the health sector are being developed to address the multi-dimensional nature of the costs and impacts. We further develop and apply a new generic conceptual framework for development-compatible climate policy planning to evaluate policy options for middle and low income countries that reduce the adverse health effects of climate change. The criteria used for comparative evaluation included economic, environment, social and institutional factors. The proposed framework, incorporating system dynamics, provides a foundation for a decision-analytical approach to support the formulation of robust climate change adaptation policies to protect human health.

Keywords Human health · Climate change · Adaptation policies · Health impact assessment

1 Introduction

The future impacts of climate change on population health include a wide range of diseases and health outcomes, from infectious diseases and non-communicable diseases to undernutrition and injuries (Confalonieri et al. 2007; Costello et al. 2009; Vineis 2010). Adaptation, broadly defined, would include all activities or interventions that reduce or prevent additional cases of diseases or deaths attributable to anthropogenic climate change and natural climate variability. Adaptation would include actions to reduce the health impacts of extreme weather events (heatwaves, floods, storms, and droughts) as well as more established public health functions such as disease control measures. Published reviews of health adaptation strategies, policies and measures (Kirch et al. 2005; Ebi et al. 2006a, b; Ebi and Semenza 2008; Kovats 2009; Huang et al. 2011; Hess et al. 2012) have so far not addressed methods to prioritise

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policy decisions, such that they are socially-inclusive and meet context-specific national development objectives, particularly pertaining to low and middle-income countries.

In this paper, we describe a new method for evaluating health adaptation policies, by providing complementary analysis and extensions to the work already developed on a new generic conceptual framework (MCA4climate) for development-compatible climate policy planning put forward by Scrieciu et al. (2014) in this Special Issue. The focus in this paper is adaptation in the health sector only. We narrowly define these as actions that are undertaken by national and local government to improve health.

2 Policy options

Policy options for adaptation are limited to traditional public health activities that focus on disease prevention and control policies in low and middle income countries. However, some options are also relevant to adaptation in high income countries (e.g. heat health warning systems). Policy options that can be included in an adaptation strategy for health (Ebi et al. 2006a, b; Ebi and Semenza 2008; Keim 2008; Kovats 2009; Huang et al. 2011) can be grouped into six categories in terms of the health protection areas being strengthened. The first category is concerned with improving, modifying or expanding health protection systems such as vector and disease surveillance systems, seasonal forecasting and early warning systems for infectious diseases. Current infectious disease surveillance systems (Nsubuga et al. 2002; Semenza and Menne 2009; Nsubuga et al. 2010) can be strengthened in order to adapt them to climate change. The second category of options involves developing and implementing community-based interventions linked to hydro-meteorological-based warning systems such as heat-health and flood-health plans. Examples of warning systems implemented in developed countries include heat-health warning systems in France (Pascal et al. 2006) and Australia (Nicholls et al. 2008).

The World Health Organization (WHO) and United Nations Development Programme (UNDP) have a series of pilot projects to increase the resilience of health sector institutions to climate change through the development and training in the use of warning systems (WHO 2010). These include the use of meteorological-based decision-support systems for heatwaves in China. Climate services (daily and seasonal forecasts) are often used in the health sector to respond to climate/weather-driven epidemics of vector-borne disease (Thomson et al. 2008). Thus, another pilot adaptation project supported by WHO/UNDP is focussed on malaria control in Kenya (WHO 2010).

The third category of policy options focuses on improving or modifying health systems infrastructure by adapting health infrastructure (hospitals and clinics) to increased frequency of extreme weather events such as heat waves and floods. There are likely to be significant costs associated with infrastructural changes (e.g. retrofitting) but the costs associated with inaction could be larger as the frequency and intensity of some extreme events are likely to increase due to climate change and other determinants of disaster risk (Foresight 2012; DEFRA 2013).

The fourth and fifth categories are concerned with strengthening environmental and occupational health regulations. These include maintaining and improving current environmental regulatory standards (e.g. water and air quality standards) and improving occupational health by enforcing current measures, or updating measures to protect workers from high environmental temperatures (Kjellstrom et al. 2009). For example, the WHO/UNDP project in Barbados focussed on strengthening the guidelines on the safe use of wastewater and household water storage (WHO 2010). The final category relates to coping with additional disease burden resulting from failure in upstream adaptation measures. They include treating the additional cases as well as improving the provision of new medication and vaccines for disease prevention (Costello et al. 2009).

Table 1 describes some of the policy instruments that can be used to implement the above mentioned health policy options. The policy instruments include market-based instruments, public investment programmes, information based-instruments, international cooperation programmes and regulations/command and control instruments.

Note that many actions which reside outside the health sector are also needed to improve health and some of these could be jointly addressed by climate change adaptation in other sectors e.g. reducing agricultural output losses, increasing access to food, increasing infrastructure resilience, improving water resources management, strengthening of coastal and river defences against floods, and improving water supply and sanitation. Table 2 lists some of the more important adaptation policies outside the health sector but with potentially significant impacts on human health. The health sector interacts and is interdependent with other sectors. Climate change adaptation policies in other sectors can also, in turn, have negative impacts on health (Table 3). Decisions concerning climate change adaptation polices often ignore the health impacts of the policies. It is important that health effects are considered in all decisions concerning adaptation policies (particularly those policies that may cause harm) by adopting the principle of "health in all policies" (Ståhl et al. 2006).

3 Developing the multi-criteria tree for the health theme

Given the complexity of adaptation options, the evaluation and comparison of health policy options are best carried out using multi-criteria decision analysis (MCDA). The MCDA approach recognizes the multi-dimensional nature of the impacts of adaptation policies. The standard methods of evaluating and comparing environmental health policies such as cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) (e.g. Hutton 2000) are inadequate for adaptation policies because they confine the impacts to only two criteria, costs and health benefits. These methods disregard other equally important multi-dimensional impacts within the health domain (e.g. health inequalities) and outside the health domain (e.g. the economy and the environment) which in turn can have impact on health. The details of the MCDA method used in MCA4climate, its rationale, advantages and disadvantages in comparison to the traditional CEA and CBA methods are given in Scrieciu et al. (2014) however the basic method is described briefly below.

The MCDA method consists of four main steps. The first step develops a set of criteria for comparing the adaptation policy options such as those described in the previous section. The second step evaluates the impact of each option on each criterion (ratings). Models or expert opinion are used to determine the ratings. The third step elicits the relative importance of each criterion (weights). These weights should add up to unity and are normally elicited from either stakeholders and/or decision makers. The fourth step integrates the ratings and the weights into a single integrated score for each option for use in comparative evaluation of options.

The rationale behind the MCDA method is that it provides a transparent approach for integrating the scientific evidence on the impacts of each policy option on the criteria with the relative importance that a decision maker assigns to the criteria. Naturally the impacts on the criteria have different units and they should be normalised before combining them with their associated weights to get an overall score for each policy options. The normalisation process thus introduces another subjective component to the MCDA process in addition to the assignment of weights. The scores can be used to rank policy options in terms of their overall performance across all the criteria. The sensitivity of the scores to uncertainty in the scientific

Table 1 Advantages and disadvantages of a range of policy instruments that can be used to implement health policy options

Market –based Instruments	Advantages	Disadvantages	Possible solutions
Subsidies or tax exemptions to pharmaceutical companies to provide medications (e.g. cholera immunization)	Preparedness to counter potential increases in climate sensitive infectious diseases	Pharmaceuticals are likely to invest only if marginal profits are high	Promote private-public partnerships
Command and control instruments			
Introduce regulations (e.g. water and air quality standards)	Ensures minimal standards	Requires resources to achieve and monitor	Provide financial support from international organizations
Public Investment programmes			
Improve infrastructure, capacity and access of primary and secondary care	Increase health system resilience during extreme weather events	Costly	Provide external support by international institutions
Carry out research to evaluate *ex ante* the effectiveness and cost-effectiveness of policies to reduce attributable health burden	Can be used for setting priorities for policies. Prevents waste of money spent on ineffective actions	Cost of research	Ensure policies are robust for a range of climate futures.
Increase healthcare workforce and investment in their training	Increase workforce resilience	Minimal	Provide external support by international institutions
Provide up-front public investment to purchase drugs (e.g. insecticide-treated bed nets for malaria) or develop new drugs (e.g. anti-malarials)	Preparedness to counter potential disease emergence in new geographical areas	Costly for investment in new drugs	Public-private financing
Information-based instruments			
Develop and implement health forecasting and early warning systems	Provide coordinated actions by targeting vulnerable population in advance	Low cost, depending on actions implemented after warning.	Develop collaborative actions with National Weather Service and regional climate fora
Increase investment in health improvement programmes	Generally effective and relatively not costly	Takes relatively long time to be effective and to reach wider population	Provide additional support from NGOs
International cooperation programmes			
Provide regional health forecasting systems (e.g. for floods, heatwaves)	Sharing of resources	Systems are not optimised to local settings	Optimise local implementation

Table 2 Adaptation policies outside the health sector that have implications for human health

Theme	Health impacts
Improving energy efficiency and saving	Direct effect on health = increasing house insulation would increase indoor temperature (reduce cold-related mortality and morbidity – positive impact) without adequate ventilation, would increase indoor pollutants (increase respiratory symptoms – negative impact)
Improving land use management practices	Indirect effect on health through land available for agriculture and impacts on livelihoods.
Increasing the share of low-carbon energy sources in fuel mix	Direct (and large) effect on health through reductions in outdoor air pollution
Capturing and storing emissions of carbon dioxide	Possible risk to health due to malfunction of carbon storage facilities
Improving coastal zone management	Positive benefit through reducing flood risk
Reducing agricultural output losses	Indirect effect on health through availability of food crops and increase household income
Increasing infrastructural resilience	Positive benefit through reducing impact of extreme weather events
Improving water resources management	Possible health effects through improved water quality and sanitation
Increasing terrestrial and marine ecosystem resilience	Possible benefits to health from “hazard control”
Reducing extreme weather event impacts	Direct positive health benefits

evidence on the impacts of the policy options on the criteria and to variations in the weights attached to the criteria, can be used to enhance transparency.

We developed criteria to be used for evaluating and comparing the health policy options, with four levels (Fig. 1). The first three levels are generic to all adaptation sectors (e.g. energy, water, health) and the fourth level is sector-specific. The latter criteria (together with their corresponding indicators) can be viewed mostly as descriptors of the generic criteria applied to human health. The level 4 health criteria are discussed in more detail below. (The indicators for the criteria are discussed in the next section).

The generic criteria are grouped, at the first level, under inputs (the costs or efforts required to implement a climate policy option) and outputs (the impacts of a climate policy option). The inputs are expressed in two dimensions (or level-two criteria): public financing needs and implementation needs, which in turn are disaggregated into spending on technology and other types of spending for the former, and allow for easy implementation and comply with required timing of policy intervention for the latter (these are the four

Table 3 Impact of health policies on other policy areas

Health Policy	Theme
Improve health systems infrastructure	Increasing infrastructural resilience
Provide heat-health warning systems	Reducing extreme weather events
Define regulatory standards for water quality	Improving water resource management
Nutritional programmes interventions	Reducing agricultural output losses

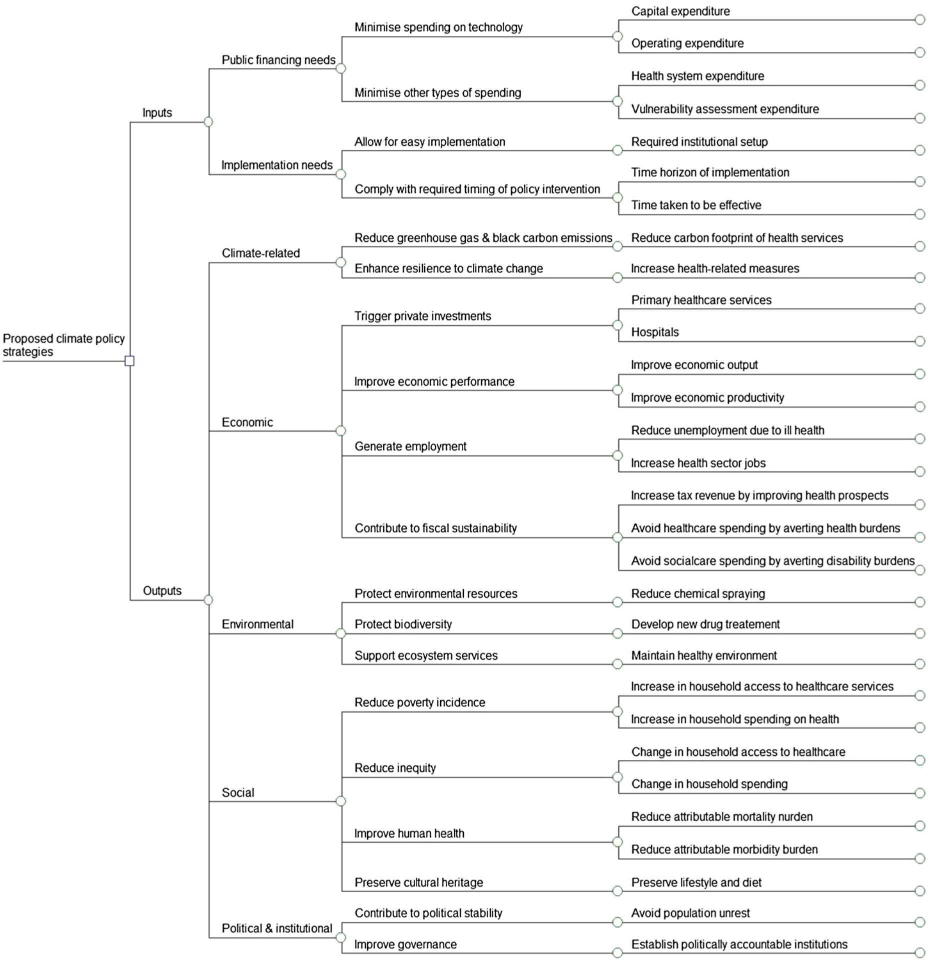

Fig. 1 Multi-criteria tree for the health adaptation framework

level-three criteria on the input side). The outputs on the other hand refer to five dimensions (level-two criteria): climate-related, economic, environmental, social, and political & institutional, to describe the likely positive or negative impacts of a policy option. These are in turn broken down into 15 level-three criteria: two on climate-related (reduce greenhouse gas & black carbon emissions, enhance resilience to climate change); four on the economics (trigger private investment, improve economic performance, generate employment, contribute to fiscal sustainability); three on environmental aspects (protect environmental resources, protect biodiversity, support ecosystem services), four on the social dimension (reduce poverty incidence, reduce inequity, improve human health, preserve cultural heritage) and two linked to the political and institutional dimension (contribute to political stability, improve governance).

The health-specific Level 4 criteria are described below, listed under their respective parent Level 3 criterion. For each of the criteria we also give at least one indicator, which are either quantitative (single-valued, multivalued or functional) or qualitative (Table 4).

Table 4 Indicators of each of the Level 4 criteria in the multi-decision criteria framework

Level 4 health-related criteria	Indicators	Type
Capital expenditure	Monetary	Quantitative
Operating expenditure	Monetary	Quantitative
Health systems expenditure	Monetary	Quantitative
Vulnerability assessment expenditure	Monetary	Quantitative
Required institutional setup	Number of organizational changes	Quantitative/ Qualitative
Time horizon of implementation	Time	Quantitative
Time taken to become effective	Time	Quantitative
Reduce carbon footprint of health services	Carbon dioxide equivalent emissions	Quantitative
Increase health-related measures	Counts in each protective area (e.g. infrastructure, surveillance)	Quantitative (multi-valued)
Trigger private investment in primary healthcare services	Monetary	Quantitative
Trigger private investment in hospitals	Monetary	Quantitative
Improve economic output	Economic wide production indices	Quantitative
Improve economic productivity	Output/input ratios	Quantitative (multi-valued)
Reduce unemployment due to ill health	Counts	Quantitative
Increase health sector jobs	Counts	Quantitative
Increase tax revenue by improving health prospects	Monetary	Quantitative
Avoid additional healthcare spending by averting health burdens	Monetary	Quantitative
Avoid additional social care spending by averting disability burdens	Monetary	Quantitative
Reduce chemical spraying	Amount of chemical per hectare per chemical type	Quantitative (multi-valued)
Develop new drug treatment	Types of drug treatment	Qualitative
Maintain healthy environment	Quality of air, water and soil for living	Qualitative (multi-valued)
Increase access to healthcare services	Increase in proportion of population who can access health services	Quantitative
Increase in household spending on health	Monetary	Quantitative
Change in household spending on health	Monetary	Quantitative
Change in access to healthcare services by gender, socioeconomic group and age	Distributional	Quantitative (functional)
Change in health spending by gender, socioeconomic group and age	Distributional	Quantitative (functional)
Reduce mortality rates	Counts per population	Quantitative (multi-valued)
Reduce morbidity rates	Counts per population	Quantitative (multi-valued)
Preserve lifestyle and diet	Lifestyle and diet	Qualitative
Avoid population unrest	Riots, strikes, demonstrations	Qualitative
Establish publically accountable institutions	Accountability and transparency	Qualitative

3.1 Inputs/Public financing needs

3.1.1 Spending on technology

There are two health-related technology expenditures of relevance under financing needs: capital expenditure (CAPEX) and operating expenditure (OPEX). CAPEX is concerned with up-front investment. This could include investment for strengthening the resilience of hospitals to extreme weather events (DEFRA 2013) or setting up health warning systems. OPEX on the other hand is concerned with continuous investment such as for maintaining the operation of health warning systems or infectious disease surveillance systems (Nsubuga et al. 2010). In some countries there is no single agency responsible for funding public capital items and operations. For example, in Australia this funding is shared by the State and Federal governments.

3.1.2 Other types of spending

There are input expenditures other than those described above. These could include expenditures associated with strengthening the health systems or with setting up teams to carry out health vulnerability assessments in order to identify and prioritise interventions. A major component of spending is also associated with training healthcare sector workforce, for example in the use of decision support warning systems, development of public health information campaigns, emergency medical treatment during heatwaves, targeting vector control interventions (WHO 2010).

3.2 Inputs/Implementation needs

3.2.1 Allow for easy implementation

There are several practical constraints and barriers to implementing climate change adaptation policies to protect health (Huang et al. 2011). These include financial constraints, technological limits and uncertain future socio-economic conditions. It is therefore important to establish the feasibility in terms of required institutional setup of any of the health adaptation policy options because although ex ante evaluations may indicate that the policy options are effective, in practice these options could be infeasible due to political sensitivities or institutional barriers. For example, heat- or flood-warning systems may require access to a health register to target high risk individuals (Schifano et al. 2009), but some primary healthcare systems may not be structured to provide this information.

3.2.2 Comply with required timing of policy intervention

There are two aspects to the timing of a policy intervention: the time take to phase the intervention and the time taken by the policy to be effective. Both of these aspects are important. For example setting up a meteorological-based warning system for extreme events takes time in terms of developing and setting up the system and providing the necessary training to operate these systems and respond in emergencies (WHO 2010).

3.3 Outputs/Climate-related

3.3.1 Reduce greenhouse gas and black carbon emissions

Reducing the carbon foot print of the healthcare sector can be considered as part of the efforts to reduce greenhouse gas (GHG) and carbon dioxide (CO2) emissions. It is estimated that the healthcare sector accounts for 8 % of total US GHG emissions and 7 % of total CO2 emissions (Chung and Meltzer 2009). Although the carbon footprint of the healthcare sector in developing and emerging countries is unlikely to be proportionally as high, nevertheless reducing their footprint contributes to the reduction in total emissions. This can also benefit health systems by reducing energy costs and other efficiency savings (WHO 2009a).

3.3.2 Enhance resilience to climate change

This criterion is concerned with upstream policy effectiveness such as to whether the policy leads to increase in the number of health-related measures (e.g. improving health services infrastructure, providing surveillance systems, introducing early warning systems for infectious diseases). For example at the global scale, the WHO and UNDP pilot adaptation project to protect human health is an example of an upstream initiative to enhance resilience to climate change (WHO 2010).

3.4 Outputs/Economic

3.4.1 Trigger private investments

Because of competing demands on public health resources, priorities are always given to current public health demands rather than to uncertain future demands. Incentives could however be introduced to encourage the private sector to invest in front line community health services and/or in hospitals, drug development and distribution. Recent analysis from the US suggests that warmer winters with climate changes are likely to be followed by earlier and more severe influenza episodes because fewer infections in a preceding warmer winter leaves a large pool of susceptible individuals in a following winter (Towers et al. 2013). It may therefore be prudent to speed up the manufacture and distribution of influenza vaccines after a mild winter to protect against severe future epidemics (Towers et al. 2013). This is an example of adaptation measure which can trigger private investment in pharmaceutical companies.

3.4.2 Improve economic performance

This criterion could be unfolded into two health-related criteria: economic output and economic productivity. The first criterion reflects the improvement in economic outputs associated with reducing the number of workdays lost due to ill health and the second reflects the improvement in labour productivity due to improved health prospects. Linking improvements in health to a decrease in the number of working days lost due to illness and an associated increase in labour productivity is commonly used in economic models (e.g. Lock et al. 2010).

3.4.3 Generate employment and improve labour productivity

At least two health-related criteria could be associated with increasing employment and productivity. The first considers increased employment and productivity due to improved health and wellbeing, and the second criterion considers the creation of additional jobs in the health sector for developing and implementing the adaptation and mitigation options (although this is likely to be minor). Some health policies could affect distributional aspects of employment, i.e. cause differential changes in employment across gender, age groups and socioeconomic groups. For example, introducing new interventions to reduce child malnutrition (educating and supporting women and small scale farmers) are more likely to create jobs for women than men.

3.4.4 Contribute towards fiscal sustainability

Public health measures and interventions are in general provided by the state and are therefore dependent on tax revenues and public spending. Three health-related criteria can be used in relation to improving fiscal sustainability. The first accounts for increasing tax revenue associated with improved health prospects and the remaining two criteria account for the avoidance of additional spending on health and social welfare by averting disease and disability burdens.

3.5 Outputs/Environmental

Because health-related adaptation policies can have relatively small impact on the environment, the three relevant environmental criteria are grouped together for exposition purposes. Reducing the use of chemicals for chemical spraying (e.g. indoor residual insecticides) to control disease vectors can protect environmental resources. Although health adaptation policies may not have an impact on protecting biodiversity, preserving biodiversity on the other hand can have indirect benefits for human health in terms of the development of new medicinal treatments as an example (De Bremond and Engle 2014 in this Special Issue). Likewise, health adaptation policies have a small impact on supporting ecosystems services at the macro-scale but the impact could be significant at the micro-scale. Ecosystem services can have many indirect benefits for human population health by providing a healthy environment through maintaining good water quality and reducing pesticides and chemicals, as well as the more direct benefits on health and wellbeing from contact with nature (Pretty et al. 2007; Parkes and Horwitz 2009).

3.6 Outputs/Social

3.6.1 Reduce poverty incidence

Reduction in poverty incidence is encapsulated by two health-related criteria. The first criterion captures the increased access to healthcare services and the second criterion captures changes in household spending on health.

3.6.2 Reduce inequity

There are also two relevant health-related criteria associated with the reduction of inequity. These mirror those of poverty incidence. The first criterion is the change in access to healthcare services across gender, age groups and socioeconomic groups. The second criterion is the change in health spending also across gender, age groups and socioeconomic groups.

3.6.3 Improve health

The commonly used metrics for measuring health and well-being are DALYs (Disability Adjusted Life Years) and QALYs (Quality Adjusted Life Years). Both are generalized health measures which are primarily used to integrate health burdens across diseases, age groups and gender. Some of these measures have inbuilt value judgements on disease-weights and age-weights which have generated strong debates. In a multi-criteria analytic framework it is natural and makes more sense to work with raw measures of health burdens (e.g. number of deaths, disease incidence or prevalence) rather than with generalized measures of health. This is so because value judgements can be introduced by policy makers using the multi-criteria decision analysis approach. Raw mortality and morbidity data may also be the only health outcome data that are available in relation to the health benefits of a specific policy. There are two main criteria for health: mortality and morbidity burdens. In practice, any quantitative health information that is available can be used. Although the above evidence-based process of collecting cause-specific health data is intensive and time-consuming, the data are important to address health inequalities.

3.6.4 Preserve cultural heritage

There are no obvious health-related criteria but preserve lifestyle and diet could be one such criterion. There is also good evidence that cultural landscapes are important for well being (Tweed and Sutherland 2007; Gifford et al. 2011).

3.7 Outputs/Political and institutional

3.7.1 Contribute to political stability

The relevant health-related criterion is avoiding population unrest associated with widespread incidence of disease and ill health. Population unrest is sometimes associated with increases in food prices.

3.7.2 Improve governance

This is concerned with establishing publically-accountable institutions to develop, manage and monitor the application of health policies. This is extremely important for population health.

4 Methods of assessment

4.1 Health impacts

There are several methods which can be used for ex ante evaluation of the future health benefits of adaptation policies. This is a complex task and it uses information that is modelled for the relevant population and/or policy and would be contingent on future scenarios of climate and other factors. The evaluation of current public health policies can be undertaken and such information should be used in the multi-criteria decision analysis. Although it may not be reasonable to assume that future effectiveness is similar to current effectiveness, in the absence of information to the contrary this is our assumption. In addition, information on current effectiveness can be included in a climate change impact assessment to quantify the benefits to future health of the implementation of adaptation policies under a given range of climate and social futures. In practice, this is not often undertaken because of the very large number of possible future climates and health futures.

One method to estimate the burden of disease due to environmental factors is comparative risk assessment (CRA) approach (Lopez et al. 2006). The CRA method has been used to estimate the health impacts of observed climate change in 2000 (McMichael et al. 2003). The public health co-benefits of climate change mitigation strategies have been quantified for 2030 using the CRA approach (Friel et al. 2009; Markandya et al. 2009; Wilkinson et al. 2009; Woodcock et al. 2009).

The CRA approach takes a simplified one-dimensional perspective of the association between climate and health. The assessment would follow the following chronology: a climate policy would modify population exposures of risk factors (relative to the business as usual scenario in the absence of the policy but in the presence of climate change) and the incurred changes in population exposures would in turn modify health impacts. The health impacts are then aggregated additively across several exposure-health outcome pathways at the same point of time. Form the modelling perspective, there are two main advantages of the CRA approach: (i) it can be easily implemented if appropriate exposure-response functions (relative risks) are available, and (ii) baseline and future projected disease burden data are widely available from the World Health Organization (WHO 2009b; Mathers and Loncar 2006) up to 2030 (although only for major diseases, and not for important health outcomes such as injuries or death from flooding). One of the weaknesses of the CRA approach however is its simplistic view of the climate-health interactions. Standard epidemiological methods (like the CRA) are not able to describe the complex interactions between climate and health incorporating non-linear interactions and feedback loops and there is a need to investigate alternative methods such as systems approach to model this complexity (e.g. Vineis 2010; Xun et al. 2010). One key weaknesses of a systems approach, however, is that it is handicapped by the lack of data for model parameterisation.

Other methods of health impact assessment include the use of micro-simulations models (Rutter et al. 2011). In these models, the life courses of a cohort of hypothetical individuals forming a synthetic population are simulated probabilistically over a long time. Each individual undergoes transitions to life events (healthy and disease states) from life to death. The outputs of micro-simulations models are simpler to understand and present than those of life-table based models because they are based on the aggregating the health outcomes of single individuals.

4.2 Non-health impacts

The methods for estimating the non-health impacts of climate change health-related adaptation policies should consider the multiple interactions between population health, the economy and the environment. Non-health effects can be considered as co-benefits of specific policies. For example, improvements in access to water and sanitation have been shown to increase access to education for children and increase the time mothers can spend with their children.

Effective health-adaptation policies would reduce current and future climate- and climate change- attributable health impacts. Climate change can have an impact on labour productivity (Kjellstrom et al. 2009). This in turn can affect other aspects of the economy such as labour costs, labour supply, private sector competitiveness, etc. Macro-econometric models can take these factors and others into account. They are used to determine the economic consequences of these reductions in health burdens (e.g. Koopmanschap et al. 1995). These models are determined from time-series observations of macro-economic data. Examples of macro-econometric models which could be potentially used for this purpose are the E3MG (energy-environment economy at the global level) and the global vector autoregressive (GVAR) models (Barker et al. 2010; Pesaran et al. 2004). These models model key macro-economic variables at the country and multi-country level and consider interactions between them. It can be used to model the wider economic impacts of health policies (e.g. in relation to GDP).

Tools such as life cycle assessment (LCA) can be used to determine the impacts of health-related adaptation policies on the environment. LCA tools have been used to assess the impact of healthcare products and services on the environment (Kaiser et al. 2001). They determine the impacts of all stages of a health policy, from cradle to grave. The applications of the tools are more relevant to advanced healthcare systems where the systems can have big environmental footprints.

We argue that any assessment of health-related climate change adaptation policies should follow the recommendations on critical issues for climate policy analysis that underpin the MCA4climate methodology (UNEP 2011a, b; Scrieciu et al. 2013, 2014). These include:

(i) Future macro-level assumptions. These are required to generate the future scenarios of greenhouse gas emissions, economic growth, population growth and thus future climate projections. It is important to establish the sensitivity of the assessments to some detailed macro- (and country-level) socio-economic and governance assumptions and to the departure from future climate projections.
(ii) Technological innovation, learning, dynamics and feedback. Economic, social, environmental and ecological systems are inherently dynamic. They change considerably with time over the time horizon of analysis. By their nature, these systems cannot be simply described by one-directional, static casual pathways between inputs and outputs. They are essentially governed by multiple feedback loops which would have strong bearing on the stability of their responses to climate shocks and disturbances.
(iii) No-regret options for mitigation and adaptation. Climate change mitigation and adaptation measures can have co-benefits and co-harms and these should be taken into account in the overall assessment of impacts. Some mitigation options can have unintended negative health consequences e.g. decarbonising the built environment (Davies and Oreszczyn 2012).
(iv) Monetary and non-monetary evaluations. Because environmental, health and social impacts cannot all be given a monetary value due to ethical and other philosophical considerations, standard methods which transform all impacts across several dimensions into a single metric (currency) are inappropriate. This provides the rationale for using MCDA.
(v) Discounting. Because the future impacts of policies are very sensitive to the choice of the discount rate, the selection of the discount rate is important. In addition to the usual strong debate in the literature on the rationale for setting specific discount rates for costs, there is a parallel debate in the health impact assessment literature on appropriate discount rates for health impacts. In the WHO Global Burden of Disease health statistics, the burdens are presented at 0 % and 3 % discount rates (WHO 2004).
(vi) Uncertainty. It is important to deal with uncertainty along the whole chain from uncertainty in future climate to the uncertainty in impacts. Using central estimates of impacts is conservative because it assumes that impacts are normally distributed about their central estimates. This is particularly not the case with extreme events.

(vii) Time horizons. There is a need to explore different time horizons (short and mid-term, up to 2050–2100) for the analysis and take into consideration the progressively large uncertainty with longer time horizons. The choice of the appropriate time horizon for health impact assessment is therefore a trade-off between the need to extend the time horizon of the analysis for the climate policies to take effects on the one hand, and the need to shorten the time horizon to reduce the uncertainty in the impacts on the other hand.

It would be beyond the scope of this paper to specify each of these issues in detail for health adaptation policies. However, the issue of dealing with risk and uncertainty which is crucial to any sound climate policy analysis is explored in more detail below with application to the health theme.

5 Dealing with risk and uncertainty

There is an active and ongoing debate on how best to deal with uncertainty in assessing the impacts of climate change and in evaluating the effectiveness of adaptation strategies to climate change in an uncertain future world. This debate has naturally resulted in several guidance strategies on the management of uncertainty in climate change impact assessments (e.g. Jones 2000; Van Asselt and Rotmans 2002; Prato 2008; Swart et al. 2009).

Methods for handling uncertainty need to take into account the types of uncertainty (Belton and Stewart 2002; Durbach and Stewart 2012a, b). We consider two types of uncertainty: (i) uncertainty which can be reduced with additional information and research and (ii) uncertainty which can be quantified but is irreducible. Examples from health of the first type of uncertainty are the characteristics of the exposure-response relationships or the capacity of populations to adapt physiologically to unusual weather conditions (e.g. prolonged hot weather conditions in temperate regions). . Examples of the second type of uncertainty are the climate and macro-economic futures. In situations where uncertainty cannot be quantified formally (e.g. using deterministic or probabilistic approaches), quantitative scenarios have been developed as a way to address these uncertainties. Fuzzy methods can also be used to quantify the uncertainty in the scenarios (Hall et al. 2007). In relation to future climate scenarios, the health impact assessments of climate policies should be carried out separately for the potential range of changes in future climate, including its effects on the distribution of extreme events. It is important in order to determine the effectiveness and opportunity costs of the policies under uncertain future climates – that is policies should be climate-resilient. The impact of future macro-economic scenarios on health is through multiple pathways: for example, a macro-economic scenario impacts health indirectly through the greenhouse gas emission-climate-health pathway and directly through the economic-health pathway.

In terms of quantifying the uncertainty in the values of health-related indicators (Table 4), the approach would depend on the type of the indicator. For quantitative indicators (e.g. capital expenditure), measures such as probability density function (pdf), lower and upper bounds, or percentiles can be used to quantify the uncertainty in the central estimate. For qualitative indicators, fuzzy sets can be used. The following examples illustrate the use of pdfs and fuzzy sets. Figure 2 characterises the uncertainty in annual operating cost (a quantitative indicator) - say of a heat-warning system. The uncertainty is represented by a log-normal distribution of mean $\$2.51\times10^4$, median $\$2.46\times10^4$ and standard deviation $\$0.26\times10^4$ (the values are notional). The characteristics of the distribution can be informed either by data or expert opinion.

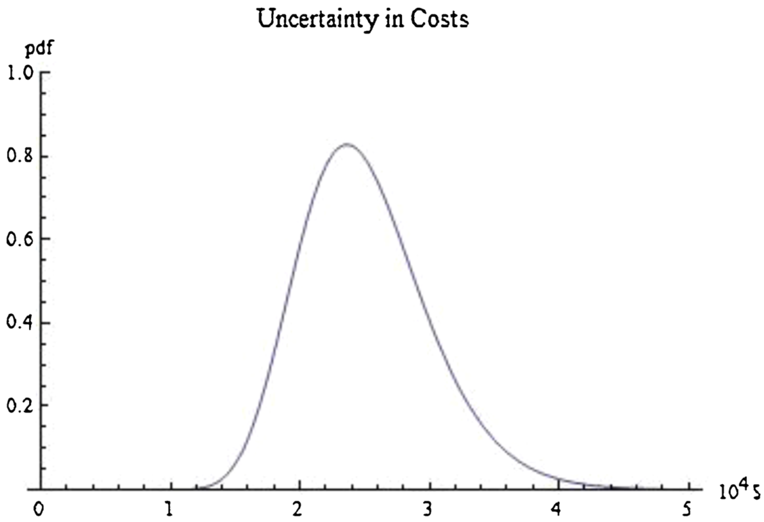

Fig. 2 Estimated uncertainty of the annual operating cost of a heat health warning system (hypothetical)

Figure 3 characterises the uncertainty in a qualitative indicator. Population unrest is used as an example. Population unrest is assumed to be either: low, medium or high. Mathematically these imprecise values are treated as fuzzy sets. The x-axis is the number of population strikes,

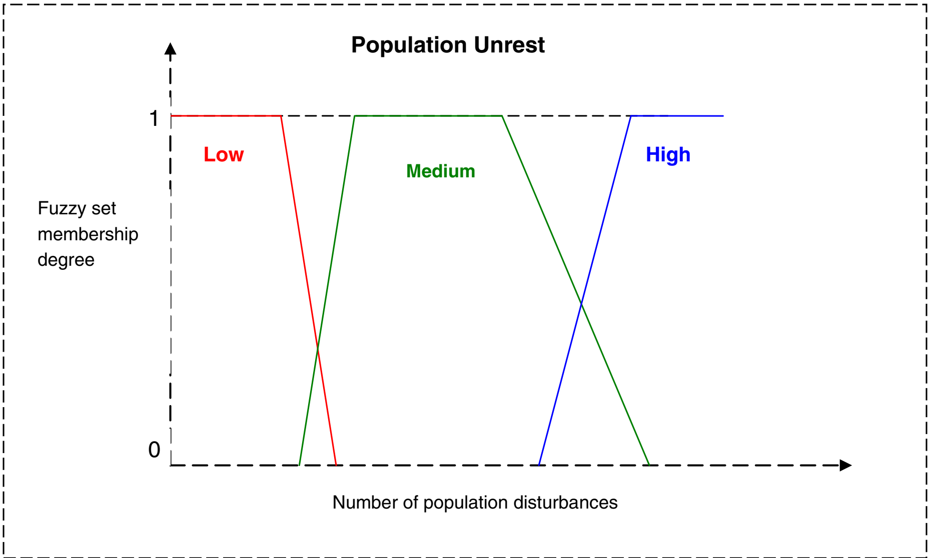

Fig. 3 Estimated uncertainty in population unrest (qualitative indicator). The schematic shows the membership degree as a function of number of population disturbances for each of three possible values of political unrest: low, medium and high. The red line is the membership function of "low population unrest", the green line is the membership function of the medium population unrest and the blue line is the membership function of "high population unrest"

riots or demonstrations (number of population disturbances) and the y-axis is the membership grade or degree of the set as a function of the number of disturbances. A membership degree of unity means that the indicator variable belongs fully to the set, a membership degree of zero means that the variable is not a member of the set; a membership degree between zero and unity implies a partial membership of the set.

In addition to characterising the uncertainty in each indicator variable, it is also imperative to use appropriate tools to propagate uncertainty through a chain of indicator variables. For example in the CRA approach described above, the attributable disease burden is calculated as the product of the population attributable fraction (PAF – proportion of the total disease burden that is attributable to the risk factor) and the total disease burden. As an illustration, Figs. 4 and 5 below characterise respectively the uncertainty in total disease burden (represented by a log-normal distribution) and in PAF (represented by a uniform distribution).

The uncertainty in the attributable disease burden is then estimated by simulating both distributions using Monte Carlo sampling and obtaining the product of the two random variables (Fig. 6).

In assessing the health impacts of a health-related adaptation policy, account should be taken of the uncertainty in the impacts under four scenarios: with and without the adoption of the policy, with and without climate change. To illustrate the issue, Fig. 7 shows a hypothetical distribution of the overall attributable disease under the four scenarios.

It is important to address uncertainty along the chain of models from climate models to health impact models. It is equally important to take into account the uncertainty in the impacts of climate change adaptation measures across all the criteria including health. In the case of parametric uncertainty, the uncertainty in the model parameters can be dealt with using deterministic single-way sensitivity analysis, deterministic multi-way sensitivity analysis, or probabilistic simulations. To deal with structural uncertainty, alternative model structures could be used and the uncertainty quantified from the range of outputs. The critical issue is to be able to quantify the uncertainty in all the impacts for use within a multi-criteria decision analytical framework to support decision-making.

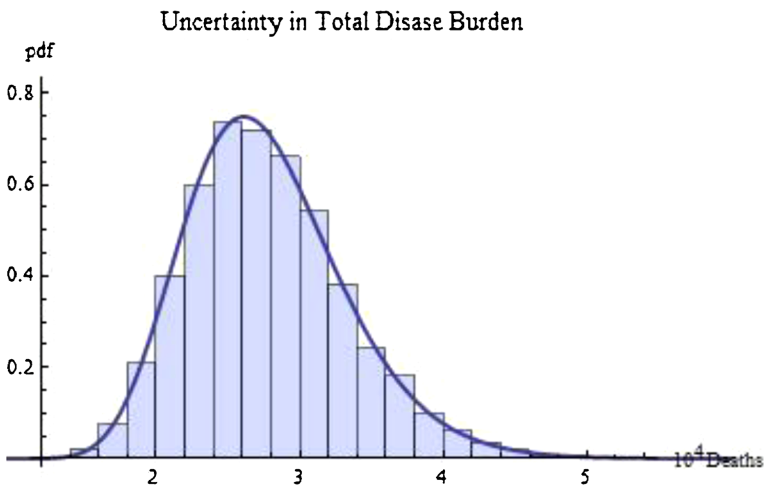

Fig. 4 Estimated uncertainty in total disease burden (deaths). Uncertainty is characterised by a log-normal distribution. The continuous curve is the theoretical probability density function (pdf) and the histogram is the empirical pdf obtained from 10,000 random numbers generated using the theoretical distribution

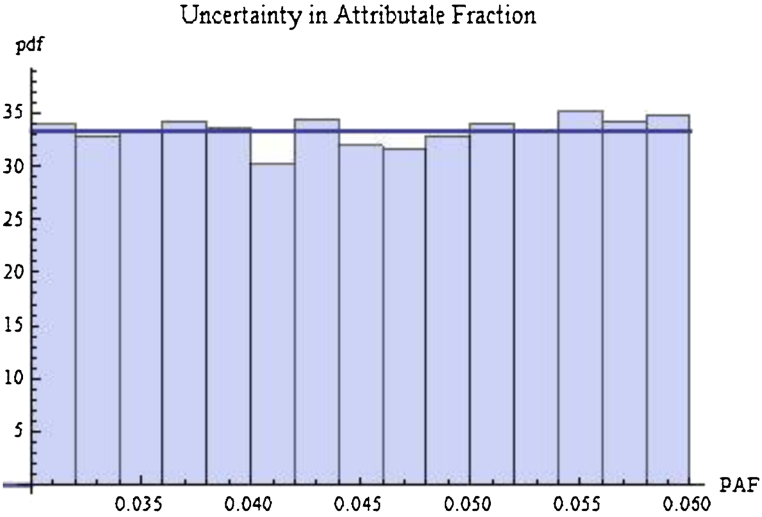

Fig. 5 The uncertainty in population attributable fraction (PAF) is characterised by a uniform distribution. The continuous curve is the theoretical pdf and the histogram is the empirical probability density function (pdf) obtained from 10,000 random numbers generated using the theoretical distribution

6 Case study

The frequency of heat wave events in India have steadily increased over the last three decades from 7 in 1981, 27 in 1998 to 70 in 2003 (Akhtar 2007). The reported health burdens associated with these events have also increased from 63 deaths in 1981, 1,658 deaths in 1998 to 1,539 deaths in 2003. A single heat wave episode in 2002 in the southern Indian state of Andhra Pradesh was associated with 622 deaths (Kovats and Akhtar 2008). It has been recognized that there is a need to develop public health preparedness plans to protect

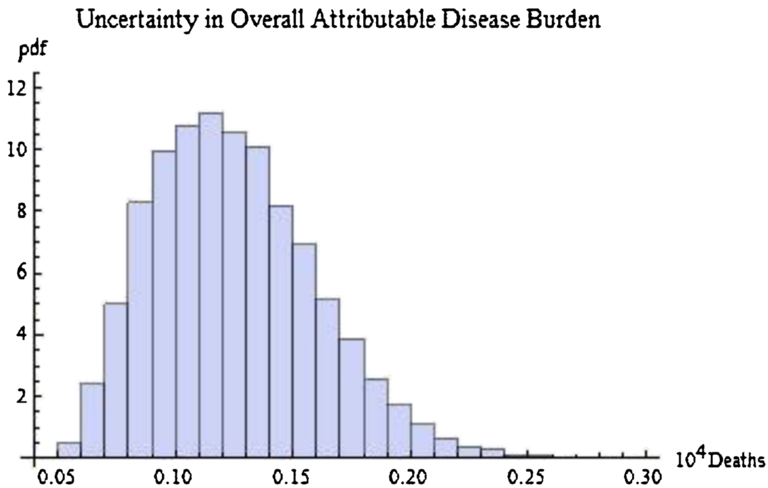

Fig. 6 The uncertainty in overall attributable disease burden. The empirical probability density function (pdf) is determined from the product of the random numbers generated in Figs. 4 and 5

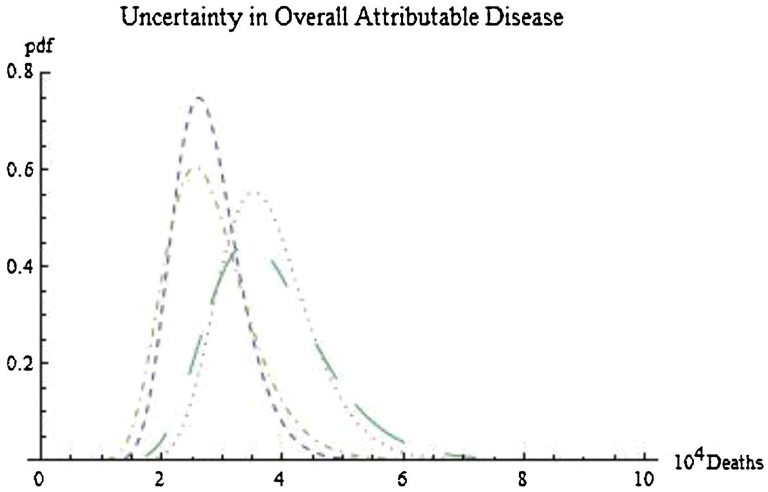

Fig. 7 The uncertainty in the overall attributable disease under four scenarios: with adaptation policy and climate change (*green*, *large dashed*), with adaptation policy and without climate change (*gold*, *dashed dotted*), without adaptation policy and without climate change (*blue*, *dashed*) and without adaptation policy and with climate change (*red*, *dotted*)

particularly urban populations in India from the increasing trends in high temperatures (Patil and Deepa 2007; Tran et al. 2013). A hypothetical case study is used below to illustrate the working of the MCDA method.

Consider a scenario where health policy makers of a medium-size Indian city are evaluating a number of options for a heat wave plan in response to increasing risk of heat waves. The policy makers need to cater for the diverse population living in their city, from those living in registered dwellings to those living in slums. The options could include, for example, the provision of (i) heat wave weather forecasts via television and radio to alert the city population, (ii) educational material via mass media on the harmful effects of high temperatures and how to mitigate heat effects, (ii) a heat-health warning system where weather forecasts are sent directly to local authorities, primary health care units and hospitals who would respond by executing actions upon receiving the heat wave alerts to target vulnerable population, (iv) subsidised air conditioning units to targeted households. An option could comprise two or more of the above options.

The MCDA method can be used to compare the alternative policy options in terms of their impacts on several health and non-health criteria. The health criteria could include the reduction in mortality and morbidity burdens (separately as two criteria or combined into a single criterion), and could be divided further into lower level criteria to characterise burdens across different populations (e.g. those living in registered dwellings, informal dwellings or slums) in order to account for health inequalities. The non-health criteria could include the impact on the environment (e.g. provision of air conditioning units would increase energy use), the local economy (e.g. advising workers and labourers to stop working during extreme hot conditions can reduce economic output and the wages of individuals). In terms of costs, the capital cost of investment (e.g. provision of air conditioning units) or running cost of implementation (provision of water bottles to slum dwellers) can be viewed from different perspectives e.g. public or individual.

The public health policy makers in this case study are faced with contrasting objectives and criteria. They can use the MCDA approach as a decision support tool to help them navigate through the myriad of options and criteria. They would commission studies to evaluate ex ante the impacts of each policy option on each of the criteria (i.e. acquire the necessary scientific evidence). They could then elicit views on the relative importance of each of the criteria amongst themselves and/or other stakeholders, and then use the MCDA to rank the options in terms of their overall importance across all the criteria. Naturally the selection of the criteria and the weights attached to the criteria could have a strong influence on the ranking of the options.

7 Conclusions

Many countries are beginning to develop adaptation policies in order to protect human health from extreme weather events and climate changes. It is important that the best available evidence is used to assess the various policy options available using a comprehensive and systematic framework that allows for the formulation of climate robust, pro-development and effective health measures. It is also important that the health benefits for adaptation actions in other sectors is recognised and incorporated into climate decision making. Multi-criteria decision analysis provides a more comprehensive method for evaluating and comparing health adaptation policy options than the standard methods of cost-benefit and cost-effectiveness analysis because the impacts of these options are essentially multi-dimensional (Scrieciu et al. 2014, in this Special Issue).

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