Bringing health and the environment into decision making: the Natural Capital Approach

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Executive Summary

Planetary Health seeks to meet the health needs of present and future humans without compromising the natural systems on which that health depends[1]. To achieve this aim, society has to adopt a way of making decisions that not only considers their narrow financial costs and benefits, but also their broader effects on human health and the natural environment. Only by bringing all of these elements together can we both understand the financial drivers of business behaviour and the wider set of influences upon human wellbeing.

The paper overviews the measures, often called 'metrics', available to governments and businesses to understand the health and environmental consequences of alternative decisions and investments. These metrics provide a scientific understanding of the wider effects of change. The paper then shows how these metrics can be brought into conventional economic decision making so they can be considered on a level playing field with other costs and benefits. This approach to understanding decisions from both a business and a wider social wellbeing perspective is commonly referred to as the Natural Capital Approach.

The paper consists of three sections, followed by a brief conclusion, and is structured as follows:

- Starting with the human aspects of Planetary Health, we first provide a review of measures of human health and wellbeing. Following an initial focus on the assessment of physical health impacts of challenges such as environmental pollution and hazards, we then highlight the merits of additionally considering the positive impacts of the environment on human health. This discussion expands our focus from simply physical health to include mental health and wider measures of wellbeing. These metrics allow the decision maker to understand the diverse public health consequences of different decisions, or indeed the effects of not making any decision and allowing other factors to determine human health and wellbeing;

- We then move on to consider the environmental aspects of Planetary Health by reviewing measures of environmental status including both quantity and quality metrics. Again this allows the decision maker to see the consequences of different decisions, including inaction. This discussion highlights the great diversity of measures associated with change in the environment and the problem of assessing and comparing such metrics;

- Finally we examine how these health and environmental metrics might be brought into government or business approaches to decision making. The Natural Capital Approach has been developed as a way of bringing health and the environment into conventional economic decision making. This provides a framework for including and translating these metrics for even handed consideration alongside all the other issues which decision makers have to consider, such as the economic benefits and costs of different decisions.

1.0 Health Metrics

1.1 Introduction

A wide range of metrics have been developed to understand and measure changes in human health, many of which are relevant to the health consequences of changes in the environment. Many of these metrics are already captured in tools, frameworks and datasets produced by global bodies. Key frameworks are summarised here, with a brief description of common population health metrics. Much of what is currently measured concerns disease and injury, rather than health and wellbeing. We therefore take this opportunity to also highlight the role of the environment in promoting good health and wellbeing. We discuss how a balanced approach to health metrics in the context of environmental change and sustainability could reflect the complex interdependencies that underpin Planetary Health.

1.2 Existing Frameworks & Indicator Sets

One of the most important collections of global health metrics is produced by the World Health Organisation (WHO) Global Burden of Disease (GBD) Project.[2] This reflects a focus on measures of 'disease' as opposed to 'health' (the conceptualisation of health is discussed in 1.4). The GBD uses national and international data sources to measure a very wide range of population disease and injury outcomes, including rates of communicable and non-communicable diseases, mortality, health-related behaviours, and risk factors. Work on the burden of disease from environmental risks estimates that 23% of global deaths each year are related to environmental causes.[3] These impacts include, for example, an estimated 2.8m deaths per year due to non-communicable diseases associated with outdoor air pollution, 370,000 deaths due to flooding and other causes of drowning, and over half a million deaths due to malaria (Prüss-Üstün et al. 2016).

The WHO also produces a Global Reference List of 100 Core Health Indicators, intended to summarise global priority health measures.[4] These are not framed as environment-related health measures, but a number of the indicators are relevant, such as the mortality rate from air pollution level in cities. Others are more indirectly environment-related, such as *"Insufficient physical activity in adults"* (discussed in 1.4). Work has also been carried out to link health outcomes in the GBD to the UN Sustainable Development Goals (Fullman et al. 2017). Along with an overall goal to deliver "Good Health and Wellbeing" (Goal 3), the Sustainable Development Goals include a large number of health indicators, from natural disaster deaths to overweight prevalence in children aged under 5 years[5].

Many other organisations compile global indicator sets including health measures from a variety of sources (often including WHO GBD), such as the World Bank[6] and the UN Human Development Programme.[7] Amongst more environmentally-focussed programmes, the Yale Environmental Performance Index[8] captures a range of environmental sustainability indicators, such as nitrogen use efficiency, or the state of fish stocks, but also includes five indicators on environmental risk exposures presenting a direct human health hazard. These are unsafe water, unsafe sanitation, household (indoor) air pollution from solid fuels, ambient (outdoor) particulate matter, and ambient ozone pollution. These indicators are drawn from the WHO GBD, the source for much comparative global health data.

In summary, the Global Burden of Disease and other collections of health metrics with relevance to the environment generally focus wholly, or largely, on environmental hazards and consequent disease, injury and mortality – not health or wellbeing. This traditional focus views the environment primarily as a set of hazards that present a direct or indirect human health risk. The current approach therefore largely positions health in environmental sustainability in terms of how we may mitigate population disease/injury risks through hazard reduction and health protection measures.

1.3 Metrics

The simplest forms of health metrics are those capturing a population measure of disease, injury, death or disability. These may be measures of *prevalent* (current) cases, such as the proportion of a population currently diagnosed with Type 2 Diabetes, or *incident* (new) cases over a specified period of time, such as the rate of new cases of malaria per 1000 population per year. *Mortality rates* capture the 'incidence' of death, often sub-divided by cause of death. Mortality rates may also be translated into *life expectancy*. Prevalence and incidence measures are often age/sex-standardised to account for the substantial effect of demographics on population health measures (e.g. higher rates of heart disease in older populations). Similar metrics to those for health outcomes can be used to indicate population health risks or behaviours, such as the proportion of the population currently meeting guideline levels of physical activity.

The *Population Attributable Fraction* (PAF) is used to allocate a proportion of the cases of a disease or deaths to a particular risk factor. This measure indicates the proportion of cases that would not occur if the risk factor were reduced to an idealised scenario (not necessarily zero). For example, the WHO GBD estimates the PAF for diarrhoeal diseases associated with inadequate drinking water to be 34%; therefore if the entire population had access to adequate drinking water, it is estimated that global diarrhoeal diseases would decline by 34%.

A variety of measures use prevalence/incidence rates alongside other data or models to estimate the economic cost or value of disease, mortality, health states or behaviours. These measures can portray direct healthcare costs related to treatment and management of a condition (e.g. estimated at Intl$825 billion per year for diabetes (Non-Communicable Disease Risk Factor Collaboration 2016)). Economic valuation can also be applied to estimate the total societal *cost-of-illness*, additionally taking into account lost productivity, loss of years of life through early mortality, and loss of quality of life.

The WHO GBD project uses one of the primary measures of cost-of-illness, using *Disability Adjusted Life Years (DALYs)* as a key metric alongside raw mortality rates. DALYs reflect both years of life lost due to mortality, and years lost due to disability or disease. A similar measure, the *Quality Adjusted Life Year (QALY)* is also used in health economic studies, often to value the effects of interventions, where 1 QALY gained is one additional year lived in 'full health' by one person. Both measures require weights, which adjust the value of time lived with illness or disability such that a year lived with a certain condition or in a specific health state is worth a specified proportion of a year lived without illness or disability. Measures may also weight the value of a year of healthy life differently at different ages. These weights are derived through a variety of methods, and future gains/losses of healthy years of life can also be subject to discounting (where current health is valued more highly than future health). These 'cost-of-illness' measures are subject to debate, and have also been critiqued in terms of being insensitive to inequality (Whitehead and Ali 2010, Arnesen and Nord 1999, Williams 1999). However, the measures do have some advantages, especially when health gains are to be offset against the costs of, for example, environmental intervention. This issue of the importance of commensurability of measures for considering health and the environment is discussed in Section 3.

1.4 Promoting a balanced approach

How we define health has significant impacts on what is measured, and how. An important and often-quoted definition of health, from the establishment of the World Health Organisation in 1948 is:

> *"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"* (WHO 1948)

Since 1948, numerous suggestions for update and augmentation of the definition have been made. In defining *Health Promotion*, the 1986 Ottawa Charter stated that:

> *"To reach a state of complete physical, mental and social well-being, an individual or group must be able to identify and to realize aspirations, to satisfy needs, and to change or cope with the environment. Health is, therefore, seen as a resource for everyday life, not the objective of living." (WHO 1986)*

More recently, an alternative definition has proposed health to be *"the ability to adapt and to self-manage"* (Huber et al. 2011). Positioning human health outcomes in environmental hazard contexts – air pollution, water quality, communicable disease and so on - is extremely important. We must also consider how future environmental change is likely to impact upon hazards and the health outcomes concerned. However, it is clear that most health metrics are actually 'disease metrics'. Measures of global health impacts of environmental conditions generally have a narrow, hazard-risk-disease/mortality focus, and do not even properly reflect the breadth of the original 1948 definition of health. A more balanced view would consider human health and environmental health as mutually dependent; the essence of Planetary Health. Alongside the significant direct risks to health from environmental conditions, we can consider more indirect relationships, the opportunities for health *and wellbeing* that our environments present, and issues of social, environmental and intergenerational equity. Importantly, we can also consider how our health-related outcomes and activities can have deleterious or beneficial environmental impacts themselves.

These interconnecting, cyclical relationships are depicted in Figure 1. This highlights that interconnections exist between environmental and health-related policies, and that pro-environmental policies can directly impact human health, and improve environmental conditions, also indirectly benefitting health. For example, policies supporting increased active travel (usually walking or cycling) have multiple potential benefits to the health of humans and the environment. These include reduced carbon emissions, improved urban air quality, and promotion of everyday regular physical activity (de Nazelle et al. 2011). Conversely, health promoting policies may have negative impacts on the environment, with direct and indirect impacts on human health. For instance, increased prescribing associated with ageing populations and improved healthcare systems can lead to the release of pharmaceuticals into sewerage systems, with consequences for wildlife, ecosystems and humans (Depledge 2011).

Whilst these concepts are not entirely novel (having been raised in concepts such as 'Ecohealth' and 'OneHealth'), the era of Planetary Health recognises the importance of this complex interdependence. Work on climate change and population health has highlighted that many of the actions for mitigation or adaptation can actually have health *co-benefits* (Watts et al. 2017). There is a clear opportunity to consider more holistically the interconnections between environmental sustainability and human health and wellbeing. The concept of wellbeing is conceived of in many ways, but there are now internationally standard metrics for measurement of population subjective wellbeing (including quality of life, happiness, anxiety and life satisfaction). These have been robustly developed to reflect the economic literature on subjective wellbeing (Dolan, Peasgood, and White 2008), and have been adopted by the OECD (OECD 2013). In turn, research has indicated the potential importance of good quality environments to promote subjective wellbeing as captured by these metrics (White et al. 2017).

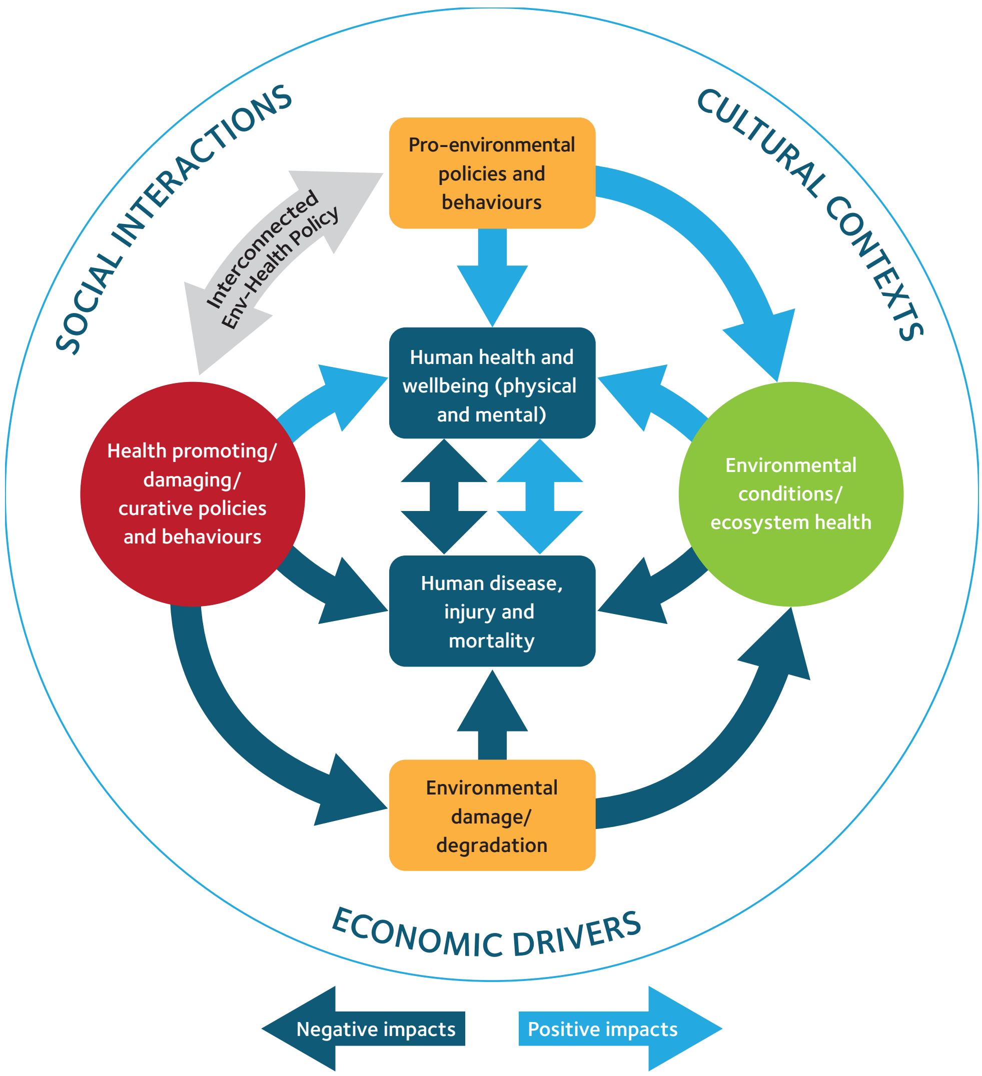

Figure 1. Interconnections between environments and human health

Reflecting these wider definitions of human health and wellbeing, there is scope to consider the value of *good environmental conditions for human health,* as well as considering environmental risks and how we might reduce hazards. International research increasingly indicates the positive value of good quality environments – both natural and built - for the health and wellbeing of the population (Hartig et al. 2014, Grellier et al. 2017, Jackson et al. 2013). Relevant metrics could include, for example, mental health and wellbeing-related outcomes associated with natural environments, and the environmental determinants of health-promoting physical activity, such as walkable cities. Figure 1 emphasises the importance of considering environment-health interconnections in the context of social interactions, cultural settings, and economic drivers of the underlying processes. A good example here is the interaction between positive health impacts of good quality urban environments and socio-economic inequalities. There are suggestions that good quality environments may to some extent help to rebalance the health damaging impacts of socio-economic inequality (Mitchell et al. 2015, Wheeler et al. 2015). However, it is also possible that urban environmental improvement (such as 'urban greening') could have unintended consequences of gentrification and increased inequality; this warrants consideration and monitoring (Cole et al. 2017).

Finally, the issues of multiple environmental exposures and multiple vulnerabilities, which may have opposing or complementary health impacts, need to be considered. 'Exposome' approaches (Wild 2012) typically consider the combined health impacts of exposure to multiple chemical pollutants, and may also incorporate exposures to other hazards such as noise and temperature extremes. We need to recognise and allow for the fact that environmental conditions may have both positive and adverse health impacts, which may be synergistic or antagonistic. For example, management of urban parks for biodiversity may improve their value for rest, relaxation and physical activity, but may simultaneously increase exposure to allergenic pollen and vector-borne diseases. Individuals and populations may have multiple vulnerabilities, including existing poor health, and experience inequalities of gender, ethnicity, race, income and so on. These vulnerabilities in combination with multiple environmental exposures make for complex webs of health-environment interconnections and feedback loops. Whilst it is challenging for health metrics to thoroughly capture this complexity, it should at least be acknowledged. Continuing to primarily position health in the context of environmental hazards itself risks over-simplification, and missing an opportunity for a more comprehensive positioning of environment-health interconnections.

Table 1 (see **Annex 1**) indicates a compendium of the types of metrics that could start to reflect a more balanced view of health and wellbeing in the context of environmental sustainability. The table includes both traditional disease and risk indicators and wider health, wellbeing and health-related environment indicators. This latter part of the table is somewhat aspirational, as many indicators do not have globally available, consistently measured data. There are some areas for which global metrics are nascent, such as the WHO urban greenspace indicator (WHO 2016). Other measures may be challenging to produce, but are still worthy of consideration and development, such as the quantity of biologically active pharmaceutical products entering river and marine ecosystems. Note that the final rows of Table 1 also consider a further metric; the translation of improvements in health into economic value measures.

In Section 3 we discuss the pros and cons of different health metrics, contrast these with environmental metrics, and consider the challenges of bringing these into conventional approaches to decision making. As part of this we highlight the case for an economic valuation approach to assessing changes in both health and the natural environment.

2.0 Environmental Metrics

Just as human health is multidimensional, so is the natural environment. Accordingly a variety of metrics have been developed to measure the different aspects of environmental status and change. Some of these are well developed and provide useful information. For example, many key global environmental change threats are well understood and have mature metrics which have been assessed across many locations and over considerable periods. A case in point concerns climate change, which is now arguably the most intensively researched scientific phenomena globally. This is reflected in an established and intensively scrutinised set of metrics (IPCC, 2014a). Because climate and weather measurements have been collected and calculated for long periods of time at locations around the globe, scientists have been able to use these to provide estimates of future climate for different parts of the world well into the future.

However, while some environmental metrics are well developed and commonly accepted, this situation is not true for all measures. For example, our understanding of the world's biodiversity is far from complete. Here simple metrics such as population numbers are inadequate as they do not tell us about the viability of that population. This has resulted in a number of competing metrics for assessing biodiversity change including extinction rates (Rockstrom et al., 2009a), habitat areas (Leadley et al., 2014), the IUCN Red List of Threatened Species (IUCN 2017) and a variety of per species viability measures (Thomas et al 2004; Clements et al 2011; Ackakaya et al 2011).

Accepting this caveat, Table 2 (see **Annex 1**) builds on and updates prior work for the Rockefeller Foundation–Lancet Commission on planetary health (Whitmee et el., 2015) to provide an overview of key environmental change issues, their impacts, selected metrics for the evaluation of change and sources for those measures.

An immediate observation from Table 2 is the diversity of metrics required to adequately assess the consequences of environmental change. This diversity generates a substantial challenge for policy and decision making. This challenge becomes more demanding where a given change or decision would affect both the environment and human health. In an attempt to meet this challenge some countries are developing repositories of multiple metrics. For example, the National Audit Office provides a diversity of environmental and sustainability metrics for the UK (NAO, 2015). This suite of measures not only considers national level environmental metrics, such as those shown in Table 2, but also extends to consider physical and mental health as well as wellbeing indicators such as those listed in Table 1, as well as linking to indicators of progress towards the UN Sustainable Development Goals.

3.0 Bringing health and the environment into decision making

3.1 The challenge

Health and environment metrics help us to examine the effects of a particular change upon the issue to which the metric relates. For example, the appropriate health metric could help reveal the 'cost-effectiveness' of an investment in road safety in terms of the number of road traffic injuries avoided for a given budget. Similarly the malaria metric could indicate the cost-effectiveness of an investment in malaria prevention, and so on. However, because a road traffic injury is very different to contracting malaria it becomes more difficult to allocate a health budget between competing ends. Examining Table 1 shows that nearly every metric is measured using different units, which make comparison across metrics challenging. Attempts to develop uniform metrics, such as QALYS, which relate different health states into a single measure, go some way towards this. In principle such measures can be used to help allocate a general health budget to maximise its overall effectiveness. However, even summary measures such as QALYs cannot, on their own, answer more fundamental questions such as how much of society's limited resources should be allocated to health and how much to other important issues including the environment and all the other crucial contributors to human wellbeing, such as education, employment, social security, transport infrastructure, etc. For this we need a measure which is comparable across all of these sources of value.

Similar challenges beset environment metrics. The cost-effectiveness of flood prevention schemes, air quality improvements, or policies to reduce carbon emissions is relatively straightforward to assess; the effect (measured by its metric) is compared with the cost of the scheme. However, determining which of these options represents a better way to spend a pre-determined environmental budget is difficult using environmental metrics such as those given in Table 2 as again virtually all of these are measured using differing units. As before, once we attempt to address wider questions such as how society's finite resources should be allocated across environmental enhancements, health improvements, and all of the other determinants of wellbeing, we need to translate these different metrics into comparable measures.

This need for a common measure becomes even more pressing once we acknowledge the interconnections within and between most of those determinants of wellbeing. For example, a change in one part of the natural environment typically effects other parts of the environment; it is an 'integrated system'. So, a policy to clear forests for farming might appear to be a good approach to reducing hunger. However, if this change occurs in the wrong location then it can result in major water pollution incidents (say from agricultural chemicals) or flooding (from soil erosion and loss of water storage). As can be seen, the issue of location is very important when any change to the environment is considered and this is a key challenge for decision making (Bateman et al., 2013). However, there is a more fundamental issue here; the unintended consequences of decisions can have major impacts on human health and wellbeing. These 'trade-offs' have to be set against the benefits of any potential investment if we are to really understand its true, net value. Furthermore, any decision takes resources away from other options for investment, entailing 'opportunity costs' in terms of the foregone value those alternatives could have brought. This means that we should always consider alternative investments when making any decision.

3.2 Incorporating Planetary Health into government and business decision making

Any attempt to promote Planetary Health through bringing human health and environmental sustainability more centrally within decision making has to address the issues raised above. Health and environmental metrics are useful for understanding the effect that a given investment might have. However, if we wish to influence more fundamental and important decisions concerning the allocation of society's finite resources between different uses, and even to argue that more should be spent on health and the environment, then we need to address the problem of comparability across outcomes. As part of this we also need to acknowledge that any action can have trade-offs (and that these vary between locations) which have to be considered if we are to understand the true value of that decision. And also we need to consider other investments if we are to use our limited resources wisely. Only by addressing these challenges can we hope to provide a way of making better decisions which addresses the multitude of pressures which governments have to balance when allocating finite budgets across competing ends. In effect there is no choice but to convert health and environmental metrics into information which is compatible with standard economic approaches to decision making. Any alternative approach maintains the status quo of health and environmental metrics merely being the means of assessing the effectiveness of pre-determined budgets. In contrast, ensuring such metrics are made compatible with standard economic decision making ensures that they can also be introduced into business decision making, massively increasing their potential impact.

In response to these challenges researchers from across multiple disciplines have worked with those from both the public and private sector to develop ways of bringing health and the environment into conventional economic decision making. This is most commonly known as the 'Natural Capital' approach, which we summarise in Figure 2. Here, at the top left of the figure we see the ultimate energy and material inputs to the system (the sun and earth) generating nature's capital (those assets, such as air, water, fertile soils, etc., upon which all human wellbeing is ultimately dependent) and the natural processes (such as climate regulation, water and nutrient cycling, etc.) which maintain those assets. Moving across the figure to the right we see that the combination of natural capital and processes produces a wide array of 'ecosystem services' such as plant growth, fibre production and even medicinal resources. While some of these ecosystem services are of value in their own right (e.g. the wonder inspired by wild species), the major value to humans is derived through their combination with the services of a range of human, social, manufactured and other capital within economic production. This yields a plethora of highly valuable goods and services which are crucial to human health and wellbeing, including stable supplies of food and water, materials, genetic information, defence from hazards, etc. As shown in the penultimate column, these are most natural assessed through a wide variety of good-specific natural units and metrics. While these are important measures of output and provision, as we have discussed, the comparability of these metrics is challenging. This has therefore led to the development of a wide variety of methods for translating these metrics into common units conveying the wellbeing generated by changes in these goods and services. While in principle this could be assessed using any transferable, comparable unit of wellbeing, by far the most common approach is to use economic value as the common unit of account.

Economic values are already widely used in both health and environmental assessments and indeed failure to use monetary units seems likely to result in the under-valuation of health and particularly environmental benefits which are often treated as if they are free and consequently over-used and under provided for. Box 1 provides a brief review of methods for the economic valuation of health and environmental changes. The use of economic values readily allows government and business decision makers to understand the costs and benefits of alternative investments. For government this allows common unit comparison of potential health and environmental investments with their spending in other areas such as transport, defence, etc. For businesses they can see how changes in their own investments affect social values, the trade-offs between the two and the potential for altering this balance in ways that could generate social benefits, enhance their own status and improve their profitability (Bateman et al. 2015).

The lower part of Figure 2 shows the use of this information in decision and policy making. Economic estimates of costs and benefits are assessed (sometimes alongside metrics of particular interest) and appraisals of the net value of a given action are made. Best practice requires that alternative uses of the resources concerned should also be considered to assess the opportunity cost of going ahead with any particular investment. Appraisals can also capture the distribution of costs and benefits across society; an issue which is often of particular interest to decision makers. Other key appraisal issues include the challenges and approaches of implementation (what are the consequences of implementing a decision in different ways, for example through regulation or various forms of incentives) and assessments of the responses to change that people are likely to adopt (i.e. avoiding the error of thinking that people's behaviour will not alter as circumstances change). These appraisals provide a major input to the decision process which should also consider any wider issues (including information gaps in the appraisal process, the degree of risk and uncertainty involved, etc.). Once a decision is made it is then passed for implementation, for example by introducing the regulations, incentives and behavioural response measures identified at the appraisal stage. Depending on the decision taken, its implementation can affect the goods and wellbeing generated by the economy as well as the natural capital and ecosystem services upon which it draws, thereby influencing future policy and business decisions so that the overall system is dynamic and feeds-back into itself.

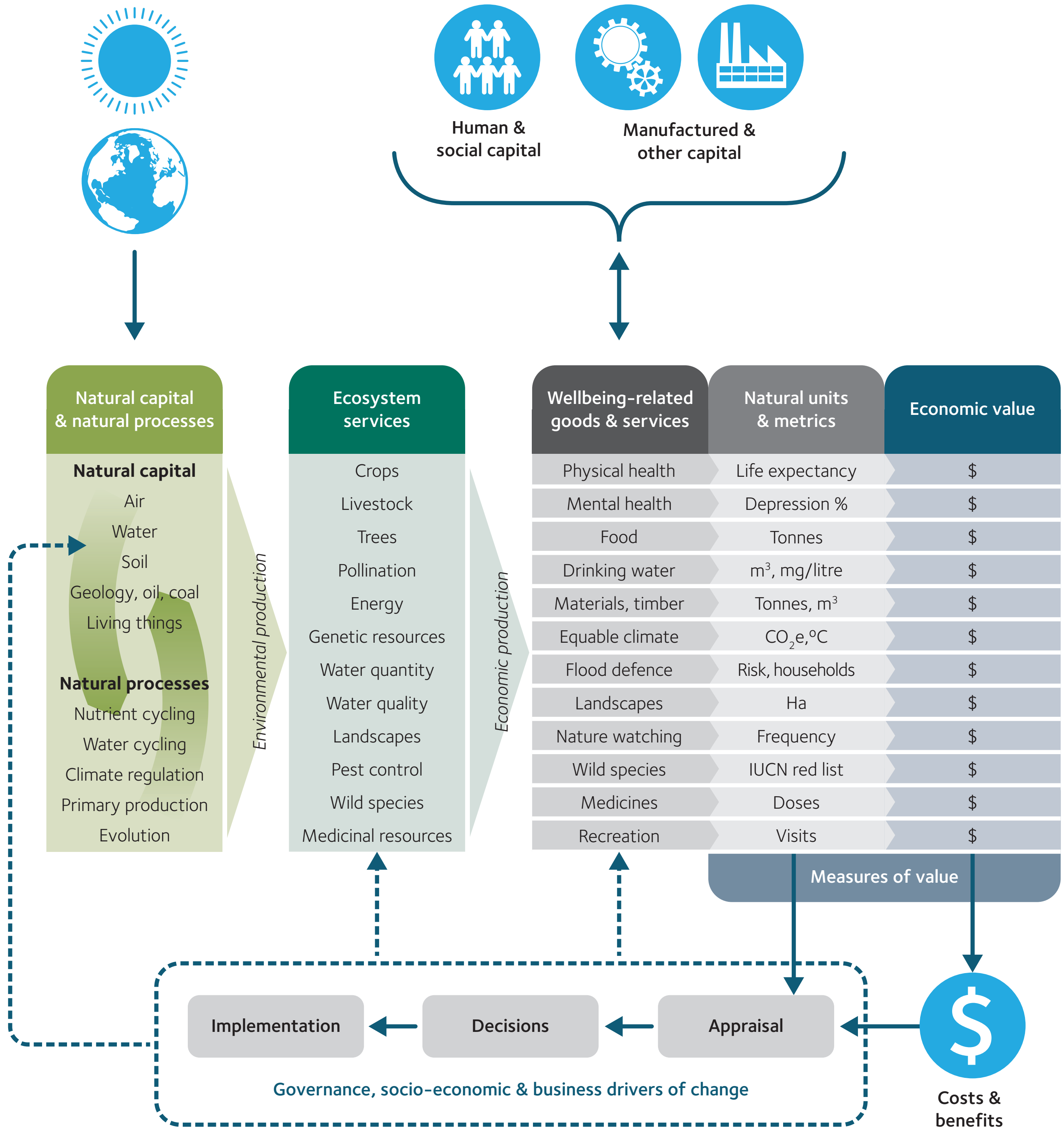

Figure 2: The natural capital approach:
Bringing health and the natural environmental into economic decision making.

The natural capital approach explicitly recognises the multiple trade-offs that arise from decisions involving health and the environment. Furthermore by translating those various effects into the common unit of economic value we have an approach to decision making which recognises the key challenges to allocating the finite resources available to decision makers. However, the explicit recognition of the various decision making challenges which are the basis of the natural capital approach provide a powerful argument for its use as the basis of the ongoing and future work of the Rockefeller Foundation Economic Council on Planetary Health. A recognition of the finite nature of resources and the inevitable trade-offs which alternative uses of those resource imply is crucial to any attempt to position human health within both the environmental sustainability debate and more general real-world decision making.

Box 1: Methods for converting metrics into economic values

Prices and values are often not the same thing. The proof of this difference is commonplace, for example some of the most valuable recreation sites in the world are free to enter. This zero entrance price in no way equates to the value of these resources and any decision maker who ignores this difference is likely to make poor decisions. Economic research has sought to provide the value evidence required for good decision making by developing the following methods:

- *Production Function Methods:* Many ecosystem services provide valuable but unpriced inputs to the production of market goods, e.g. rainwater and crop pollination are vital for food production. One widely applicable strategy for valuing these services is to examine the change in value of production generated by nature's services (Barbier 2007, Hanley and Barbier 2009). Fezzi et al. (2014) undertake such a 'production function' analysis to estimate the value of ecosystem services such as rainfall and temperature on food output and examine the consequences of future climate change.

- *Revealed Preference Methods:* The value of many non-market, unpriced ecosystem services can be revealed by examining people's behaviour. For example, while many outdoor recreation sites are free to access, visiting them often imposes travel and time costs on individuals, thereby introducing a trade-off between those costs and the wellbeing individuals experience from visits from which values can be assessed (Bateman et al., 2016). Similarly, such 'revealed preference' methods have used people's house purchase decisions to value reduced levels of road, rail and air noise (Day et al., 2007) and better air quality (Chay and Greenstone, 2005), while studies of safety equipment purchases (Jenkins et al. 2001) and wage rates across risky jobs (Arnould and Nichols, 1983) have been used to estimate values for health risk reduction (see also critiques in Viscusi and Aldy, 2003; Andersson and Treich, 2011).

- *Stated Preference Methods:* Values can also be estimated by presenting people with choices between alternatives which, for example, offer different improvements in health at various costs. Neidell (2018) discusses how such choices can be used to estimate a Value of Statistical Life (VSL), a measure commonly used for a variety of policy decisions. Recent research has also sought to translate common health metrics, such as QALYs, into economic values to help health authorities allocate available funds towards effective treatments (Baker et al., 2010; Donaldson et al., 2011; Robinson et al., 2013; Pennington et al., 2015). Particular attention has also been given to the estimation of values for key groups such as the elderly or children (Alberini et al., 2010). The same approach can be applied to valuing environmental changes While there is active debate regarding the use of stated preference methods (Carson et al. 2001, Day et al. 2012, Hausman 2012, Haab et al. 2013), they are in some cases the only available valuation method and are more suitable in situations where those providing valuations are familiar with the good in question, understand the consequences of change and strong incentives to answering questions in an unbiased manner.

- *Value transfer methods:* The methods outlined above can require considerable investments of time and resources to implement robustly. Consequently researchers have developed techniques to transfer values from previous studies to obtain lower cost, rapid valuations which can be adapted to the conditions of a given decision making situation (Plummer 2009, Bateman et al. 2011a, Brander et al. 2012, Richardson et al. 2015).

- *Cost-based (non-valuation) methods:* While values are the ideal inputs to decision making, in some circumstances cost estimates provide sufficient information for a decision to be made. For example, Heal (2000) discusses the case of whether or not to take the valleys supplying water to New York out of polluting agricultural production. Here the cost of building a water purification plant far outstripped the cost of paying farmers to change to methods which avoided pollution. This does not provide a value for all of the ecosystem services that would be provided by an unpolluted watershed (including better habitats for wild species, improved recreational quality, etc.) but it does provide a lower boundary on that value, fully justifying taking the watershed out of polluting agriculture (a decision which was subsequently implemented). Similarly the avoidance of damage costs have been widely used to provide useful information to decisions concerning flood assessments (Barbier 2007, Barbier et al. 2013). Care has to be taken with cost based methods though. The costs of attaining desired improvements for biodiversity can be calculated (UK-NEA 2011, Bateman et al. 2013) but these must not be taken as indicators of the value of such conservation.

Conclusions

The Natural Capital Approach presents an opportunity to consider health and the environment alongside other factors when making policies and taking decisions. It promotes a broad conceptualisation of the multiple ways in which human health and wellbeing and the environment are interconnected, beyond traditional models of environmental hazards and disease. The use of a common economic framework permits explicit consideration of trade-offs, and wider benefits and costs relating to health and the environment, which may otherwise go unaccounted for in decision-making.

Annex 1: Tables

Table 1: A Compendium of Health Metrics

Indicator	Outcome	Potential data sources	Metric	Sources
Exemplar Disease & Risk Indicators				
Lower respiratory infections associated with ambient air pollution	Morbidity & mortality	WHO Global Burden of Disease	Disability Adjusted Life Years (DALYs) (relates to SDG 11)	Prüss-Üstün et al. 2016, SDSN 2015
Malaria incidence	Morbidity & mortality	WHO Global Burden of Disease	DALYs, mortality rate (SDG 3 indicator)	Prüss-Üstün et al. 2016, SDSN 2015
Road traffic injuries	Injury-related morbidity & mortality	WHO Global Burden of Disease	Road traffic deaths per 100,000 population (SDG 3 indicator)	Prüss-Üstün et al. 2016, SDSN 2015
Urban heat exposure	Heat-related morbidity & mortality	Global Urban Heat Island Data Set, NASA Socioeconomic Data & Applications Center	Average summer day maximum / night minimum land surface temperatures	CIESIN - Columbia University 2013
Sanitation coverage	Morbidity & mortality associated with contaminated water exposure	WHO & UNICEF Joint Monitoring Programme	% population with a safely managed sanitation service (SDG 6 indicator)	WHO & UNICEF 2017
Exemplar Health, Wellbeing and Health-Related Environment Indicators				
Commuting through active travel modes	Physical activity and related health outcomes; reduced urban air pollution	Censuses, population travel surveys, road traffic count surveys	% of working population commuting actively	de Nazelle et al. 2011, Saelens and Handy 2008
Greenspace availability	Access to green space with associated mental and physical health outcomes	Landcover maps, municipal landuse maps, population census data	% of population living within 300m of greenspace of minimum 0.5ha	WHO 2016
Measures of pharmaceuticals and derivatives in aquatic ecosystems	Water quality with potential ecological and human health impacts	Direct water sampling, modelling based on pharmaceutical use	Concentrations of pharmaceuticals/active metabolites in aquatic systems	McDonald and Riemer 2008
Equity of access to (or residence within) good environmental conditions	Multiple health-related environmental inequities	Integration of spatial socio-demographic population data and multiple health-related environmental indicators	Distributional indicators e.g. availability of greenspace for highest and lowest 20% of population by socio-economic status	Mitchell et al. 2015, Cole et al. 2017
Value of physical activity in the outdoor environment	Environmental support for physical activity and consequent health outcomes	Visit surveys	Physical activity in the outdoors → metabolic equivalent (MET) minutes → Quality Adjusted Life Year (QALY) gains → monetary value	White et al. 2016
Economic valuation of changes in health and wellbeing	Changes in health and wellbeing	Intervention-specific evaluation, models, observations of behaviour, surveys and experiments	Monetary value, including values of QALYs and the Value of Statistical Life (VSL).	Vandermeulen et al. 2011, Lovell and Taylor 2013, Baker et al. 2010, Donaldson et al. 2011, Alberini et al. 2010, Neidell 2018.

Table 2: A compendium of environmental change metrics

Environmental change issue	Impact	Example Metrics	Sources
Climate change	Increase in temperatures, changes in rainfall patterns, changes in the frequency and duration of extreme weather events. Impacts on food production, infrastructure, habitats and biodiversity, water quantity, quality and flooding, and direct health impacts such as heat stress.	• Atmospheric concentrations of greenhouse gases, particularly carbon dioxide (CO_2 ppm), methane (CH_4) and nitrous oxide (N_2O). • Mean global temperature change (oC)	IPCC 2013, 2014b, Sanford et al. 2014, Steffen et al. 2015.
Freshwater availability	Agriculture and food production impacts and dislocation; water poverty; migration and political tensions.	• Global water use (thousand km3) • Population affected by water shortage (millions)	Kummu et al. 2010, UKNEA 2011, El-Zein et al. 2014, Steffen et al. 2015.
Changes in land use	Mainly from conversion of agriculture. Loss of wild species habitat and associated biodiversity, undermining agricultural resilience, dislocation of regional microclimates.	• Proportion of land used for agriculture (%)	Steffen et al. 2015.
Soil erosion and fertility loss	Threats to food production from over-intensive agricultural systems. Excessive tillage.	• Revised Universal Soil Loss Equation (RUSLE) • Soil organic carbon (mg/cm3) • Biomass of soil functional guilds	Montgomery 2007, Lambin & Meyfroidt 2011, Mace et al. 2005, Steffen et al. 2015, USDA 2014, Zhang et al. 2017.
Nitrogen and phosphorus pollution	Supports agricultural production but generates major changes to ecosystems including nutrient pollution to waterways and marine environments.	• Global fertiliser use (nitrogen, phosphorus, and potassium; thousand tonnes).	Corvalan et al. 2005, Steffen et al. 2015, Rockstrom et al. 2009a.
Toxic chemical pollution and exposure	Short and long term health damage; morbidity and mortality.	• As per health metrics	Whitmee et el. 2015, UNEP 2013, Daughton and Ternes 1999.
Overfishing	Threat to marine food supplies. Knock-on impacts upon food webs. Destruction of marine habitat (e.g. coral reef) and associated biodiversity.	• Global marine fish capture (million tonnes of fish) • Estimates of population size and viability	Pope et al. 2010, Steffen et al. 2015, FAO 2016.
Ocean acidification	Threat to food webs, krill, shellfish, fisheries, higher sea mammals. Food supply impacts. Global losses of marine habitat (e.g. coral reef) and associated biodiversity.	• Global ocean acidification (pH). • Mean hydrogen ion concentration (nmol/kg) • Global marine fish capture (million tonnes of fish)	IPCC 2013, IGBP 2013, Steffen et al. 2015.
Biodiversity loss	Threatens the regulation of many ecosystem-level processes and consequent provision of multiple essential goods and services for humanity ranging from food to medicines.	• Vertebrate biodiversity index value (1970=1) • Extinction rates • Habitat areas • IUCN Red List • Species viability measures	Thomas et al. 2004, Worm et al. 2006, Rockstrom et al. 2009a, Ackakaya et al 2011, Clements et al 2011, Cardinale 2012, CBD 2014, Leadley et al. 2014, WWF 2014, Whitmee et el. 2015, IUCN 2017.

Environmental change issue	Impact	Example Metrics	Sources
Forest loss	While some temperate forests are increasing in area, major tropical forests are in severe decline. This causes direct loss of forest resources	• Tropical forest loss (compared with 1700 baseline) (%)	Steffen et al. 2015.
Primary energy use	Major contributor to climate change from fossil fuel combustion.	• Energy use (exajoules). • Atmospheric concentrations of greenhouse gases, particularly carbon dioxide, methane and nitrous oxide. • Atmospheric concentration of CO_2 (ppm) • Mean global temperature change (oC)	Steffen et al. 2015, Chapman 2014, Blankart 2017.
Non-linear changes in all of the above	Past trends may disguise 'thresholds' beyond which impacts may rapidly accelerate, sometimes resulting in 'tipping point' effects where entire ecosystems are changed.	• As per the above	Barnosky et al. 2012, Regime Shifts Database 2017.
Interactions between multiple environmental threats	Where multiple threats interact to generate effects which are greater than the sum of their individual impacts.	• As per the above but across multiple metrics. • Novel chemical cocktail metrics where pollutants interact.	Whitmee et el. 2015, Barnosky et al. 2013, Regime Shifts Database 2017.
Economic valuation of environmental changes	Gains and losses in wellbeing induced by changes in the environment	• As per the above but using the single metric of economic values.	Bateman et al. 2002, 2011b, Freeman et al. 2014.

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Endnotes

1 This definition pays deliberate homage to the clarity of the Brundtland Commission definition of sustainable development (WCED, 1987).
2 http://www.who.int/topics/global_burden_of_disease/en/
3 http://www.who.int/quantifying_ehimpacts/publications/preventing-disease/en/
4 http://www.who.int/healthinfo/indicators/2015/en/
5 UN Sustainable Development Goal 3 (SDG3) is "Good Health and Well-Being", but health features explicitly or indirectly in many of the other SDGs (see WHO: http://www.who.int/sdg/infographics/en/).
6 http://datatopics.worldbank.org/health/home
7 http://hdr.undp.org/en/data
8 http://epi.yale.edu

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