

Supplementary Material to:
A systematic approach to assess human well-being
demonstrated for impacts of climate change
(Short title: A systematic approach to assess human well-being)

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Table S1: Theories and concepts included to identify relevant livelihood elements. The table corresponds to Figure 1, main text.

Theory	Maslow's Theory of Human Motivation	Basic Needs Approach	Human Development	Human Scale Development	Capability Approach	Ap-Human (HS)	Security	Sustainable Livelihoods
Sources	[1]	[2, 3, 4]	[5, 6]	[7, 8, 9, 10]	[11, 12, 13]	[14, 15]		
Main points	Independent categories of needs are related to distinct behavioral and associated with individual fulfillment (Pyramid of Needs)	Developed to tackle mass poverty, taking into account sustainability and broader progress, rather than focusing on increasing income alone	'An influential operationalization of the Basic Needs Approach; distinction between needs, which are universal and finite, and satisfiers, which may differ across space and time	The resources (capabilities) a person has access to determine the possibilities to convert them into functions. Capabilities express a person's freedom to put their aspirations into practice	A state of HS is achieved when poverty in any relevant domain of livelihood is absent.	HS is achieved when poverty in any relevant domain of livelihood is absent.	Security	Sustainable livelihoods can be achieved through access to a variety of livelihood resources in different contexts. Main requirements are listed, but may differ at other scales.
Subsistence	<ul style="list-style-type: none"> ■ immediate physiological needs 	<ul style="list-style-type: none"> ■ food, water 	<ul style="list-style-type: none"> ■ subsistence 	<ul style="list-style-type: none"> ■ life 	<ul style="list-style-type: none"> ■ food ■ resource stocks as useful resources for livelihoods 			

Table S1: continued

Shelter	<ul style="list-style-type: none"> ■ protective housing
Health care	<ul style="list-style-type: none"> ■ physical health ■ health care ■ safe birth control ■ bodily health ■ bodily integrity ■ health ■ good health ■ physical ability
Education	<ul style="list-style-type: none"> ■ basic education ■ understanding ■ skills ■ knowledge
Social protection	<ul style="list-style-type: none"> ■ safety ■ protection ■ social claims
Economic stability	<ul style="list-style-type: none"> ■ economic security ■ economic security ■ capital base

Table S1: continued

Political Stability/Participation	■ autonomy	■ participation ■ freedom	■ control over one's environment	■ political security
Security of person	■ safety	■ non-hazardous work environment	■ protection	■ personal security
Social cohesion	■ esteem/respect	■ non-hazardous physical environment	■ physical security	■ security in childhood
			■ affiliation	■ community
				■ network ■ social relations ■ associations ■ affiliations

Table S1: continued

Other aspects	<ul style="list-style-type: none"> ■ love (af- fection, belonging- ness) ■ self- actualization 	<ul style="list-style-type: none"> ■ primary rela- tionships 	<ul style="list-style-type: none"> ■ affection ■ idleness/creation ■ identity 	<ul style="list-style-type: none"> ■ emotions ■ senses, imagination, thought ■ play 	<ul style="list-style-type: none"> ■ environmental security
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Table S1: continued

Theory	Quality of Life (QoL)	Subjective Well-Being (SWB)	Millennium Ecosystem assessment	Dimensions of Poverty	Measurement of Economic Performance and Social Progress
Sources	[16, 17]	[18], cited in [19]	[20]	[21]	[22]
Main points	As a measurable approach QoL puts into practice a construct of (subjective) well-being	Four components make up the measure, namely pleasant/unpleasant effect, life satisfaction and domain satisfaction. The latter as measurable, external domains, are relevant for the present analysis.	With ecosystem services at the core of the MEA, the multiple linkages between aspects of human well-being and ecosystems through provisioning, regulating, and cultural services are outlined.	Based on an extensive survey of poor people, dimensions of deprivation and poverty are identified, which reverse elements are those most needed to improve people's well-being.	The Commission's aim was to identify the limits of GDP as an indicator of economic performance and social progress and to consider additional information required for relevant indicators of social progress.
Subsistence	<ul style="list-style-type: none"> ■ food 	<ul style="list-style-type: none"> ■ Sufficient nutritious food ■ Access to clean air and water ■ Adequate Livelihoods 		<ul style="list-style-type: none"> ■ Food 	

Table S1: continued

Shelter	<ul style="list-style-type: none"> ■ housing ■ Shelter ■ Housing and shelter
Health care	<ul style="list-style-type: none"> ■ health ■ Strength ■ Feeling well ■ Health ■ Health
Education	<ul style="list-style-type: none"> ■ intelligence ■ Education
Social protection	<ul style="list-style-type: none"> ■ safety ■ Security in old age

Table S1: continued

Economic stability	<ul style="list-style-type: none"> ■ material well-being ■ productivity 	<ul style="list-style-type: none"> ■ material resources ■ income 	<ul style="list-style-type: none"> ■ Access to goods ■ Secure resource access 	<ul style="list-style-type: none"> ■ Assets ■ Work 	<ul style="list-style-type: none"> ■ Material living standards (income, consumption and wealth) ■ Security of an economic as well as a physical nature
Political stability/Participation	<ul style="list-style-type: none"> ■ freedom of choice and action 	<ul style="list-style-type: none"> ■ Freedom of choice and action 	<ul style="list-style-type: none"> ■ Political voice and governance 		

Table S1: continued

Security of person	<ul style="list-style-type: none"> ■ safety 	<ul style="list-style-type: none"> ■ Personal safety ■ Security from disasters 	<ul style="list-style-type: none"> ■ A physically safe and secure environment ■ Personal physical security 	<ul style="list-style-type: none"> ■ Security, of an economic as well as a physical nature
Social cohesion	<ul style="list-style-type: none"> ■ community 	<ul style="list-style-type: none"> ■ social life 	<ul style="list-style-type: none"> ■ Social cohesion ■ Mutual respect 	<ul style="list-style-type: none"> ■ Peace, harmony, good relations in the family/community ■ Social connections and relationships

Table S1: continued

Other aspects

- emotional well-being
 - family friendship
 - romantic relationship self
- intimacy/friendship
 - Ability to help others
 - opportunity what an individual values doing and being
- Appearances
 - Physical environment
 - Being able to care for, bring up, marry and settle children
- Personal activities including work
 - Environment (present and future conditions)
- Self-respect and dignity
- Confidence in the future
- Peace of mind
- Happiness
- Harmony (including a spiritual life and religious observance)

Table S2: The table lists the 16 identified elements relevant for AHEAD, following the order of Figure 1 (main text). Note that some elements are split up in order to enable measurability and three additional elements have been included. Column one and two list the operable element, its definition as well as its contribution to AHEAD. The last column lists the sources and synonyms used in different approaches.

Element	Relevance	Source and Synonym
Social cohesion	Social exclusion is associated with state fragility [23] and increased rates of morbidity and mortality [24, 25].	In some form in most approaches, e.g. social cohesion [20], Community (security): [12, 21, 16].
Water availability	Water is a prerequisite for human survival and is essential for the provision of other human needs (e.g. food, energy production).	[3, 21, 20]; subsumed under subsistence needs in [5, 1]
Water quality	While the overall availability of water is essential for several aspects of AHEAD, it needs to be of appropriate quality for the different uses, especially for drinking water [26].	[20]
Calorie availability	Malnutrition can have severe health effects; lack of calories can lead to starvation, lack of specific nutrients to specific diseases. Especially children are at risk of permanent damage if they receive insufficient food and nutrients [27, 28].	[29, 12, 21, 20, 3]; subsumed under subsistence needs in [5, 1]
Air quality	Sufficient air quality is a prerequisite for human health; many excess deaths are attributed to bad air quality [30, 31].	[20, 21]; often mentioned with health or subsistence needs.
Health and health care	Health and the access to health care is important for human well-being and a prerequisite for any other activity.	[22, 12, 16, 10, 3, 14]; strength/feeling well [20]; specific reference to health care infrastructure [21, 3]
Economic Stability	Secured basic economic resources (assets, secure livelihoods) are the basis for planning ahead and feeling secure about the future. Economic insecurity due to unemployment or unstable employment conditions pose health risks [24].	Majority of approaches, e.g. economic security [22, 12, 3], capital base [14], with some overlap to other elements, e.g. access to goods [20] and material resources [29], which also refers to e.g. shelter, energy and food.
Security of Person	Personal security, e.g. feeling protected from direct violence, is important, as e.g. constant fear can lead to health problems [24].	Aspects of (personal) security are mentioned in all approaches, e.g. personal security/safety [12, 20] or safety [1, 16]

Table S2: continued

Element	Relevance	Source and Synonym
Political stability ¹	The institutional valuing of basic human rights is essential for secure living conditions. A functioning governance system can also support sustainable development [32].	In some form in most approaches, but often subsumed under other categories e.g. governance/political voice [22], democracy/political security [12].
Participation	Participation possibilities enhance the likelihood of sustainable development [33].	[5, 20, 21], often subsumed under other categories, e.g. political voice [22] (see footnote 1)
Education	Understanding is a basic need to be able to participate in any important sphere of life and contributes to higher levels of participation and better health [34]. It is also an essential prerequisite for the possibility of adaptation and sustainable development.	[3, 12, 22, 14]
Social protection	Access to support, if individuals lack the resources to support themselves is essential and can consist of institutional (state) schemes or be informal (communal). It provides an important aspect of security and support, should people not be able to support themselves.	(personal) security/safety [20, 12, 21, 16]; (communal) protection [5]
Shelter	Secure housing both affects the access to resources such as sanitation and water, but also provides protection from outside threats, security and dignity [35].	[5, 18, 20, 21]
Energy availability	Access to (affordable and clean) energy is a prerequisite for sustainable development, as energy is needed for most economic activities.	[21], further sources [36, 37, 38, 39]
Communication	Access to information and communication technologies is essential for informed decisions and participation in life, especially in an increasingly technology-driven society [40].	[41, 42].
Mobility	This refers to the physical ability to participate in society, including the economic, political and social life of the community [43]. Mobility is not only a means to an end, but has also been recognized as a need in itself [44].	[44, 45]

¹The aspects of Political Stability and Participation are strongly interlinked and the approaches often have overlapping definitions. However, the identified elements are all discussed and distinguished as important.

Table S3: Interlinkages between elements of AHEAD, outlining the main characteristics of the directed relationships denoted with 1 in the influence diagram Figure 2.

Effects of water availability on	
Water quality	Both, increases and decreases in water availability can have impacts on water quality: increased water availability, can lead to increased suspended matter and contaminants in water bodies. Additional stagnant water can lead to an increase in water-borne diseases [46]. Reduced water availability may lead to increased salinisation [47] and increased pathogen and chemical loading [48].
Calorie availability	Food production is the largest water consumer; water is a critical constraint for food [49, 50, 51]. Without precipitation for rain-fed agriculture and water resources for irrigation, crop growth is reduced.
Energy availability	Energy production relies on water for cooling, growing biomass for energy and water for hydro-power. Energy is the second-largest water consumer [52].
Political stability	[53] note that a correlation can be found between water scarcity and high intensity conflict, but not to low intensity conflicts within states. Reduced water availability has been shown to increase the potential for conflicts in some cases, however, this relationship is contested and cooperative water management is more frequent than (violent) conflict [54].
Economic stability	Adequate access to sufficient water reduces time spent to acquire water and generally raise health status, so more time can be spent on generating household income [55, 56].
Education	Access to sufficient water may increase education, as time is freed to attend school [56].
Effects of water quality on	
Water availability	Polluted water is no longer available for human use and water quality issue are often a bigger restriction for access to sufficient water than resource availability alone [24, 57].
Energy availability	Water of sufficient quality is essential for cooling and polluted water, suspended through matter, may damage turbines [58, 59].
Effects of calorie availability on	
Political stability	Famine can lead to conflict and instability, but usually if other driving forces are also present, such as human rights violations or oppressive social inequalities [60, 61].
Education	Studies have shown that undernourished children have lower cognitive functioning and diminished capacity to learn and are prone to increased school absences [28]. Though many studies support the link, [62] argues that the causality is not proven, as there may be confounding factors. But since less availability will mean more time is needed to acquire food, less time will be spent on school [62].
Effects of energy availability on	

Table S3: continued

Water availability and water quality	Making water available requires energy for moving, processing and transporting [63]. In the U.S., 1.4% of total energy consumption goes to supplying cleaned water [52], while numbers of up to 7 % have been cited globally [64].
Calorie availability	On farm energy consumption accounts for 2-5% total energy in almost all countries, regardless of development status, e.g. for farm machinery, irrigation, fertilization and their production [51]. Further energy is required for food processing [64]. Biofuel production may reduce calorie availability if agricultural land and commodities are used for biofuels.
Air quality	Energy production affects air quality at different levels. Especially the use of solid fuels for in-house energy generation results in indoor air pollution [65]. Depending on the prevailing type of energy production, outdoor air quality can also be negatively affected and total global numbers of premature deaths due to indoor and outdoor air pollution are high [31].
Education	Electrification of rural areas has shown to increase literacy significantly, as evenings can be used for studying [66]. Further, tasks such as collecting fuel wood are replaced by energy, freeing time for study [67, 68].
Health care infrastructure	The provision of health care is dependant on energy availability for several purposes, e.g. specific treatments, adequate hygiene and continuous service (lighting) [68, 63].
Security of Person	The availability of electric street lights after dark can significantly improve security, especially of women [68].
Communication	Energy/electricity input is needed to access communication infrastructure, such as (mobile) phones and the internet, as well as information media, e.g. radio or television [63].
Mobility	Transport and travel for mobility rely on fuel and energy availability; the sector accounts for about 19% of energy use globally [69].
Effects of shelter on	
Security of person	Shelter provides safety refuges from the dangers that exist outside - these may include violence but also health threats or weather impacts [35].
Effects of social protection on	
Security of Person	Social protection ensures that a person receives support of some kind, thus reducing direct threats to personal security, stemming from multiple sources which follow from insufficient funds to support needs. Causes of violence as a threat to personal security come from a variety of factors. Poverty, as well as inequality has been found to contribute. Social protection can ameliorate some of these circumstances [70, 71].
Social Cohesion	Poverty and income inequality can lead to a deterioration of social cohesion; social protection can reduce inequality and help to keep social cohesion intact [72]. Especially informal protection will increase cohesion.

Table S3: continued

Education	Having secured basic needs through social protection may increase education, as time is freed to attend school [56].
Effects of political stability on	
Calorie availability	(Political) stability - or rather the absence of it in times of war and conflict - can lead to reduction of food production and changes in distribution patterns. Often also trade routes are interrupted, leading to food shortages and famine [60, 61].
Security of person	A lack of stability can increase the likelihood of conflicts and thus reduces personal security [71, 70].
Effects of security of person on	
Political stability	High levels of crime can lead to a higher potential for revolution and lower levels of democracy [72].
Effects of social cohesion on	
Political stability	A breakdown of social cohesion could threaten democratic institutions [72, 23].
Security of person	Social cohesion has been found crucial to reduce state fragility and a lack of social cohesion can contribute to increased violence [23].
Social protection	Strong social networks make more likely the transfer of assets (informal solidarity) [45].
Effects of education on	
Participation	Higher levels of education seem to increase likelihood for voting and other ways of civic participation. Understanding seems to be key to be able to access existing channels. It also increases the likelihood for citizens to inform themselves about candidates [73].
Economic stability	Education enhances job skills, or the ability to acquire them, and thus secures better economic positions to ensure (personal) economic stability. On a higher level, better educated personnel will ensure economic reliability and availability of skilled workers to keep productivity up [74].
Effects of participation on	
Political stability	Higher rates of political participation are associated with lower inequality rates, which contribute to societal stability [75, 72].
Effects of mobility on	
Health care	Increased mobility has been found to significantly improve health status, due to better access to health care, as patients can more readily access the provided services [76].
Social cohesion	The access to transportation and mobility provides physical access to social networks [45, 43].
Effects of communication on	
Social cohesion	Access to communication infrastructure and participation, as well as active communication within the community can promote social cohesion [42, 77].

Table S3: continued

Participation	Access to information and to communication infrastructure enables and promotes participation and good governance [42, 41].
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