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Metrics of water security, adaptive capacity, and agroforestry in Indonesia

Meine van Noordwijk[1], Yeon-Su Kim[2], Beria Leimona[1], Kurniatun Hairiah[3] and Larry A Fisher[4]

Mixed agroforestry systems offer opportunities to simultaneously meet the water, food, energy and income needs of densely populated rural and peri-urban areas in Indonesia. Water flows out of upland areas provide multiple ecosystem services to downstream areas that can be part of performance-based rewards, payments or co-investment in environmental stewardship. Metrics for measuring performance and negotiating accountability need to cover river (blue), soil + vegetation (green), recycled (gray) and atmospheric (rainbow) water in relation to specific stages in the water cycle and associated services. A typology of services and prototype payment mechanisms were derived from action research in Indonesia and elsewhere in Asia by the Rewarding Upland Poor for Environmental Services (RUPES) project. The ecological metrics of landscape performance can be combined with measures of human capacity to assess and support the resilience of social-ecological systems under climate change.

Addresses
[1] World Agroforestry Center (ICRAF), Bogor, Indonesia
[2] Northern Arizona University, United States
[3] Brawijawa University, Malang, Indonesia
[4] University of Arizona, United States

Corresponding author: van Noordwijk, Meine (m.vannoordwijk@cgiar.org)

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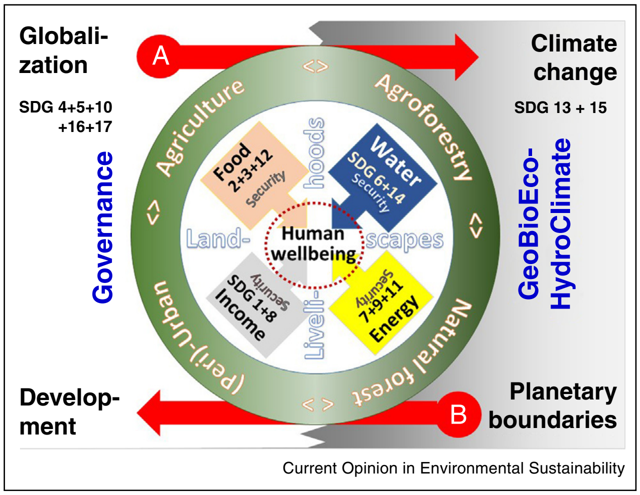
Introduction to the water, food, energy, and income nexus

Greater demand and more uncertain and irregular supply, due to climate change, define the challenge of water [1] in the Anthropocene [2••]. Rising demand is due to a growing human population increasingly living in urban and peri-urban areas, and with life styles based on greater material consumption. Because of these direct connections, key aspects of human well-being are discussed as part of a water, food, and energy nexus [3•]. Rural income security is closely connected to issues of water, food [4] and energy securities and may be an integral part of this nexus. Each of these securities can be considered as having at least four dimensions: first, excess of supply over demand, second, access by vulnerable groups to adequate supply, third, absence of factors hindering the utilization of the resource for human benefits, and fourth sovereignty and control over decisions. We propose these four securities as part of a water, food, energy, and income (WFEI) nexus. The United Nations' Sustainable Development Goals (SDGs) provides a politically legitimate framing for efforts to jointly attain these goals by managing their interactions [5]. Five of the 17 goals are primarily about equity and distributional issues; two deal with planetary boundaries and associated tipping points; the other ten goals deal with the WFEI nexus (Figure 1). Progress toward the SDG's is most likely to come from adaptive learning loops in which monitoring of current conditions and change provides evidence for identification of issues with a common understanding across stakeholders, so that there is space and impetus for innovation, integration of new options and ways of linking knowledge with action, influencing decisions at the various scale that matter from households to natiojnal governments and private sector entities.

Key to the security concept is how people and ecosystems can adapt to climate change. To increase adaptive capacity, especially in developing countries, it is necessary to synergize efforts to address the WFEI nexus and ecosystem conservation, as the need for 'supply' of ecosystem services is likely to increase over time [6]. For reasons that are partially explained by current science [7], but that may also require further discoveries of the way rainfall depends on vegetation [8••], there is an intuitive association between forests, tree planting and all aspects of the water cycle [9]. Given the WFEI nexus, we focus here on adaptive capacity and opportunities to increase water security, in its broadest sense, by land uses with partial tree cover. While there have are multiple definitions of agroforestry in current use [10], the intersection of tree cover and agricultural lands as operational definition is most readily quantified at global scale [11•].

Figure 1



Water security as part of the Water + Food + Energy + Income (WFEI) nexus, in landscapes of (peri)urban, agricultural, agroforestry and natural forest land uses in a world of globalization, climate change and Sustainable Development Goals (SDGs) (A: human influence affecting the rate of climate change; B: human influence affecting ecosystem responses to climate change).

Agroforestry links directly with traditional bio-energy (fuelwood, charcoal) [12] as well as modern hydro-energy through regularity of river flow. Agroforestry systems also contribute to food production and income, and provide flexible options for managing the associated trade-offs between production for household use and for markets [13].

Mixed agroforestry systems, intermediate in properties between open-field agriculture and natural forest, allow for diversity-based climate adaptation through increasing farmer portfolios at the farm level [14], and increasing multi-functionality of land uses in the landscape [15•]. International forest definitions use 10% tree cover as lower threshold for forests. More than 43% of all agricultural land globally, an area where 900 million people live, has more than 10% tree cover [11•]. The percentage of agricultural land with at least 10% tree cover has been increasing globally and in Southeast Asia [11•]. Efforts to reduce the rate of deforestation, such as REDD+ (reducing emissions from deforestation and forest degradation in the global climate convention) are unlikely to succeed without addressing the WFEI nexus [16]. Although the potential conservation values of agroforestry systems have been recognized, ecological benefits may vary depending on practices and location [17]. Land use and tree cover alone can be poor indicators of water services.

The limited freshwater buffer on many tropical islands adds a specific context to these issues in Indonesia. As an archipelago of more than 3000 inhabited islands, Indonesia has many parts that are susceptible to drought, flood and sea level rise [18]. Rainfall variability is highest in eastern Indonesia, with strong effects of the El Nino/La Nina cycle [18]. Low values of the Human Development Index (http://hdr.undp.org/en/content/human-development-index-hdi), rural poverty, and dependence on climate-sensitive agriculture and fisheries coincide with seasonal shortages of dependable water supplies. The increase of tourism in islands such as Bali and Lombok implies demand in sectors with higher ability to pay for water than agriculture, and increased competition for scarce resources.

Here, we first explain why metrics for water security should be defined within the context of social-ecological systems and the WFEI security issues. Then we provide a synthesis of our current understanding of the way reliable metrics of water security can be used in the broader context of co-investment by stakeholders of landscape multi-functionality. The metrics are organized by micro-climatic, meso-climatic, and macro-climatic scales for understanding beneficial and problematic roles of tree cover and agroforestry in reducing climate vulnerability. The main typology was derived from an analysis of the RUPES program ('Rewarding Upland Poor for Environmental Services they provide'), which encouraged local site teams in the adoption of improved forest, land, and watershed management practices by rural poor through rewards for environmental services (the RUPES program includes 16 action research sites in 9 countries throughout southeast Asia) [19••].

Water security in social-ecological system

Water security is defined by what are considered to be acceptable levels of water-related risk, with its many aspects of 'too much' (flooding), 'too little' (drought) and inadequate quality. Water security requires the availability of sufficient quantity and quality of water on a consistent basis, sufficient resources and knowledge to have access to and utilize water, as well as sovereignty, in a social-political setting, over water supply and distribution. Under this definition, threats to water security can originate from natural (e.g. climate change hazards and ecosystem responses to climate change) and human (overconsumption, lack of infrastructure, and skewed allocation) systems. Human systems can directly influence the rate of climate change (Figure 1, A) and also affect ecosystem capacity to respond to climate change (Figure 1, B). Human systems can also modify the level of exposure by reducing or increasing people and assets in hazardous locations, and the level of vulnerability by adaptation and intervention [20].

Metrics for water security must start with a basic understanding of the hydrological cycle in relation to land use (*So what?)*, then by identifying the likely political scale of the decision space (what are drivers of change? *Why* are