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Re-orienting technological development for a more sustainable human–environmental relationship

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Humankind's amazing innovative capacity, through the development of technology, has resulted in a tremendous expansion of civilisation but with little consideration on ecological sustainability. There is very limited understanding on the mechanism of the impacts of technology on both society and ecology. This paper proposes a conceptual framework to explicitly articulate the role of technology as a mediator of the reciprocal relationship between the eco-hydrological system and socio-economic system in catchments. It helps re-orient future technological innovation for more sustainable human–environmental relationships.

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Introduction

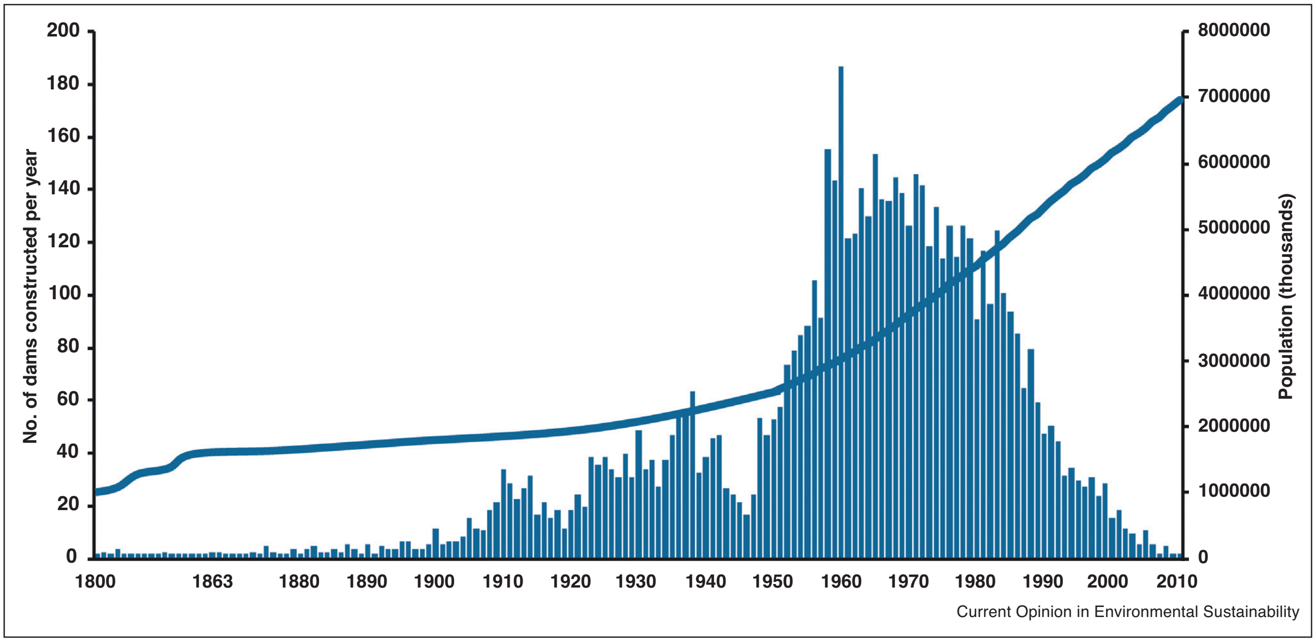
Human beings, whilst being initially shaped by nature, transform it with innovation and utilization of technology. Global propagation of technology has generated myriad artificial processes that support prosperity of human society [1]. The industrial revolution in the eighteenth century, the scientific and technological revolution in the twentieth century, the information revolution, biotechnological and nano-technological revolution at the end of the twentieth and beginning of twenty-first century have created a '*techno-sphere*' within which humans live [2]. Yet, rapid expansion of civilisation in the last 200 years showed little consideration to maintain ecological sustainability. There is escalating evidence that the human–environmental interactions in many parts of the world have become 'locked in' to unsustainable pathways [3,4]. A key global challenge is to use human's innovative capacity (technology development) to change the currently unsustainable trajectories of the global environment.

Water catchments have been considered as quintessential for economic development supported by huge scientific and technological innovation. Dams are a typical example. From the first dam in the world, the Jawa Dam in Jordan built more than 5000 years ago, to the Three Gorges Dam in China completed in 2008, the passion to subdue nature and marshall resources never ceases [5]. Since the middle of the 19th century, a mission to maximize productivity has been imposed on river basin management, and gradually evolved to the pursuit of developing large-scale infrastructures such as reservoirs, flood control and irrigation canals. The vision of utilising and shaping a river basin to its fullest potential by human forces was common in the early 20th century [5]. There are about 45,000 large dams in the world, which supply water to 30–40% of irrigated lands worldwide and contribute to 19% of the world's electricity but have also led to serious degradation of catchment ecosystems. Although the public voice against dam construction has been increasing [6] and dam construction has presented a decreasing trend since 1980s (Figure 1), over 2900 large dams are still either under construction or are planned [7].

'*Technology is as old as humankind*' [10]. There have been extensive empirical studies tracking the development of technology in sociology and for understanding complex dynamics between technology and society, and in neoclassical economics for measuring the contribution of R&D in economic growth. Only a few of these studies investigated the impact of technology on ecological systems and they were done in an implicit way in which the technological impact is explained as residual from accountable factors [11,12••]. It is widely recognised that there exists complex dynamics among technology, society and ecology, thus it is a great challenge to both analytically and normatively decipher the complexities of technological development and its impacts on socio-ecological systems.

This paper will propose a conceptual framework for measuring the impact of the development of technology on the socio-economic system and eco-hydrological system in catchments. It is hoped that this framework can assist in the development of a mechanistic framework for understanding the complex dynamics between society, technology and ecology for re-orienting technological innovation for a more sustainable global environment.

Figure 1



Dam development (in histogram) and population growth (in line) in the history. Dam data between 1800 and 2010 collected from Global Reservoir and Dam (GRanD) in NASA Socioeconomic Data and Application Centre (SEDAC) [8]. Population data between 1800 and 2010 collected from United Nation Conference on Trade and Development (UNCTAD) (http://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx) and History Database of the Global Environment [9].

Technological research review

The foundation of technological research rests on the definition of what technology is. Technology, in a broad sense, is defined as beliefs, artefacts, and evaluation routines based on its representation as knowledge [13]. The '*technology as beliefs*' perspective refers to how technology is conceived in human cognition, the '*technology as artefacts*' and '*as evaluation routines*' indicate how technologies interact with the external environment. More specifically, technology is considered as the subset of knowledge that includes artefacts, methods and practices '*to fulfil certain human purposes in a specifiable and reproducible way*' [12••]. This definition focuses on the physical perspective of a technology, which mainly refers to its functional characteristic and implementation process [13,14]. We adopt this more specific definition in this paper, and consider technology as a sub-system of the co-evolved socio-ecological system. Technological studies from different disciplinary perspectives will be reviewed in the following section to identify what we have known and what we should know for reorienting future technology developments.

Empirical study on technology

Technology is initially studied empirically. For the purpose of examining technological development in general, technological capacities are analysed by tracking representatives of technology [15]. Three representatives are commonly used: those based on resources (e.g. research expenditures, trade data), on research and design (e.g. scientific publications, patent data), and on impacts and/or outcomes (e.g. machine productivity and efficiency) [16]. Technological capacity has been very often measured as the number of patents based on their citations [15], but recently the contents of patents are analyzed with textual content analysis, creating a dynamic technological map [17,18]. These methods are intuitive and relatively easy to implement. However, the scope of technology to be studied is highly limited.

Another empirical research stream focuses on the history of technology [14]. This stream is rooted in the belief that the technological history should follow '*an orderly or rational path*' that is '*consciously directed since the beginning of history*' [19]. Empirical evidences support that technological development follows an S-curve evolutionary path and is path dependent. In general, it includes three phases: incubation during when technological development is comparatively slow, acceleration during when there are heavy research and development activities, and maturity when development of the technology has reached its physical boundaries [12••,20,21]. Multiple technological developments over time are the succession and aggregates of each individual S-curve, which represent the overall technological progress [22]. Technology is studied as a whole in these empirical studies but shows