Time-dependent environmental cost-benefit framework to support urban nature-based solutions implementation programs

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Nature-based solutions (NbS) are increasingly promoted in urban contexts for their potential to deliver multiple ecosystem services (ES) while addressing environmental, climate, and public health challenges. Nevertheless, comprehensive assessment frameworks capturing life cycle environmental impacts, economic externalities, health outcomes, and scaling effects remain limited. This study develops a consequential life cycle assessment (LCA) modelling approach to quantify trade-offs between detrimental and beneficial impacts associated with NbS interventions at urban scale. In doing so, the proposed approach accounts for spatio-temporal dynamics of ES supply and demand, negative externalities and costs, and impacts beyond the investigated NbS management phase. It is applied across multiple spatial and temporal scales on a case study combining reconstructed soils (technosol, as substrate) with urban tree and shrub planting in Turin (Italy). At site level, an ex-post pilot afforestation project on a former industrial brownfield is first assessed through LCA and business model analysis to explore environmental performance, socioeconomic trade-offs, and upscaling strategies. Carbon sequestration and air pollution removal are also accounted for and translated into human health benefits. At metropolitan scale, an ex-ante, time-dependent consequential LCA is applied to evaluate the performance of a hypothetical large-scale technosol-based NbS programme, explicitly modelling phased deployment, marginal supply dynamics, and end-of-life activities. Results indicate that NbS deployment generates substantial short-term environmental burdens, mainly driven by soil production and material handling. Detrimental impacts reach their maximum within 15 years, after which they are progressively offset by the ES generated by the NbS. Depending on design and scale, the point at which carbon neutrality is attained occurs after approximately 45 years, whereas air pollution impacts shift to a net negative outcome only after at least 60 years. Overall, this integrated framework supports evidence-based planning by highlighting long-term benefits, material-related trade-offs, and decision levers for sustainable urban NbS implementation.