Exercise as Low-Carbon Prevention: A Conceptual Framework of Healthcare Utilization Reduction and Environmental Co-Benefits in Older Adults

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Abstract. Healthcare systems contribute substantially to greenhouse gas emissions as well as hazardous waste, thus may cause negative effect to human health. Reducing healthcare utilization through health promotion may help lower the environmental burden of healthcare systems. This conceptual framework aims to estimate the environmental co-benefit from the exercise program leading to healthcare utilization reduction in elderly. A literature search was conducted in PubMed and EBSCOHost. Hospitalization, acute outpatient or emergency-type utilization, type 2 diabetes, and cardiovascular disease were used for scenario-based estimation for greenhouse gas reduction. Hospitalization showed that community-based exercise participation associated with a 46% lower hospitalization risk, equivalent to 20.7 kg CO2-e and 2.53 kg solid waste avoided per acute hospitalization-day, or 63.48 kg CO2-e and 3.27 kg waste per ICU bed-day in an upper-bound scenario. For acute outpatient or emergency-type utilization, reduction scenarios of 13% and 23% were translated into 9.88 and 17.48 kg CO2-e avoided per use, respectively. For type 2 diabetes, a 58% incidence reduction corresponded to 83.52 kg CO2-e avoided per patient-year, or 8,352 kg CO2-e annually per 100 expected cases. For cardiovascular disease, a 28% lower risk of major adverse cardiovascular events corresponded to 73.64 kg CO2-e avoided per case or 8.96 kg CO2-e per inpatient bed-day. These estimates suggest that elderly exercise may reduce avoidable healthcare utilization and produce environmental co-benefits, particularly through reduced hospitalization. Indonesian policy application requires local carbon accounting and prospective validation in primary care settings.

Keywords: Elderly, Exercise, Healthcare utilization, Carbon footprint, Waste.

1 Introduction

Healthcare systems are intended to improve health and extend life. Yet the services they provide also depend on energy, buildings, supply chains, pharmaceuticals, medical devices, transport, and waste disposal. Globally, healthcare has been estimated to account for approximately 4.4-4.6% of greenhouse-gas emissions, or more than 2 gigatons of carbon dioxide each year [1-2]. This creates an uncomfortable public-health paradox:

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healthcare responds to the health effects of climate change while contributing to the environmental conditions that intensify those effects. Climate-related heat, respiratory illness, food and water insecurity, infectious disease, displacement, and widening health inequalities may ultimately erode gains achieved by health systems [2-3].

The environmental burden of healthcare is distributed across the entire care pathway. Facility energy use and infrastructure are important, but so are procurement, medicines, diagnostic procedures, disposable supplies, staff and patient travel, food services, and waste treatment [1]. The carbon intensity of care therefore differs substantially between settings and clinical pathways [4]. An intensive-care bed-day, for example, does not have the same environmental profile as a primary-care consultation. This variation matters because prevention is unlikely to reduce every component of healthcare emission equally. It is most likely to affect the variable resources associated with avoidable visits, admissions, procedures, medicines, and complications.

Physical inactivity is a major modifiable risk factor for noncommunicable disease, functional decline, and premature mortality [5]. In older adults, regular physical activity supports mobility, balance, cardiometabolic health, and continued independence. Current WHO guidance recommends aerobic activity, muscle-strengthening exercise, and multicomponent activities that include balance and functional training [6]. These recommendations are usually justified in clinical and economic terms. A further question is whether the same interventions could also reduce the environmental burden associated with preventable healthcare use.

The reduction of incidence, severity, or complications of chronic diseases may result in the reduction of hospital utilization, such as outpatient visits, hospital admissions, medication use, rehabilitation needs, and diagnostic procedures. A review reported that higher levels of physical activity were associated with lower healthcare costs, despite the varied effect across populations, study designs, and healthcare systems [7]. As healthcare costs and carbon emissions are linked to resource use, this finding may be translated into reductions in greenhouse gas emissions. This logic provides a basis for viewing physical activity not only as a public health intervention, but also as part of a green health system strategy.

This question is particularly relevant to Indonesia. Population ageing is increasing the demand for chronic-disease management, rehabilitation, and long-term support. A predominantly specialist-led and facility-based response will be difficult to sustain across a large and geographically dispersed country. Community-based prevention is not a substitute for necessary medical care, but it can reduce avoidable demand and preserve higher-intensity services for people who need them most.

Indonesia already has community-based programs that provide promotive and preventive services for older adults, including posyandu, senam lansia and other programs under primary health centers (Puskesmas). These programs commonly include health monitoring, education, social participation, and physical activity activities for older adults [8]. One existing community-based activity that can be repositioned within this agenda is senam lansia, or elderly group exercise. Senam lansia is a low-cost, socially acceptable, and culturally familiar form of physical activity that can be delivered through community networks. Its group-based format fits the communal characteristics

of Indonesian society and may support adherence through social interaction, peer support, and routine participation. Existing discussions generally frame senam lansia in relation to physical fitness, balance, quality of life, fall prevention, chronic disease control, and social participation. However, its potential environmental value remains underexplored. If senam lansia contributes to reduced preventable healthcare utilization among older adults, it may also contribute indirectly to reduced greenhouse gas emissions from healthcare services.

This paper therefore develops a conceptual framework and scenario-based estimates linking exercise-related changes in healthcare utilization to potential environmental co-benefits. The analysis focuses on hospitalization, acute outpatient or emergency-type care, type 2 diabetes, and cardiovascular disease. The purpose is not to claim that exercise has already been shown to decarbonize healthcare, but to clarify the evidence pathway, quantify plausible magnitudes, and identify the data required for a locally valid Indonesian model.

2 Materials and Methods

2.1 Study Design

We used an evidence-informed conceptual-framework approach because no direct study was identified that measured both participation in an older-adult exercise program and the resulting change in healthcare-related greenhouse-gas emissions. The analysis therefore connected two bodies of evidence: studies estimating the effect of exercise or lifestyle intervention on healthcare utilization or disease incidence, and studies quantifying the environmental footprint of relevant healthcare services.

2.2 Literature Search and Eligibility

A targeted search was conducted in PubMed and EBSCOHost. PubMed was selected for its coverage of biomedical and public-health literature, while EBSCOHost provided access to nursing, rehabilitation, allied-health, and multidisciplinary databases available through the institutional subscription. Search terms covered four domains: exercise or physical activity; older adults and age-related chronic conditions; healthcare utilization or cost; and healthcare-related environmental impact. Terms included exercise, physical activity, elderly, older adults, diabetes, type 2 diabetes, cardiovascular disease, healthcare utilization, healthcare use, outpatient, inpatient, hospitalization, healthcare cost, carbon footprint, greenhouse-gas emission, and healthcare emission. Boolean operators were used to combine terms across domains.

The search proceeded in two stages. The first stage identified studies reporting associations or intervention effects between exercise, physical activity, or lifestyle programs and healthcare utilization, hospitalization, or disease incidence. The second identified carbon-footprint or waste estimates for healthcare activities that could serve as conversion factors [4], [7]. Eligible sources included peer-reviewed empirical studies, systematic reviews, and modelling studies that reported quantitative data relevant to at

least one side of this pathway. Studies were excluded when they focused only on athletic performance, young populations without clear relevance to ageing or chronic-disease prevention, non-healthcare emissions, or exercise outcomes without a utilization, cost, or resource-use measure. Editorials, opinion pieces, conference abstracts without sufficient data, non-English reports, and inaccessible full texts were not used..

2.3 Scenario Model

Evidence was organized into four pathways: hospitalization, acute outpatient or emergency-type utilization, type 2 diabetes, and cardiovascular disease. For each pathway, a published relative reduction in utilization or disease incidence was paired with a published carbon or waste factor for the corresponding service. Estimated avoided environmental burden was calculated as relative reduction in utilization × environmental footprint per service unit.

This calculation assumes proportional scaling. It does not distinguish fixed emissions, such as buildings and baseline staffing, from variable emissions, such as consumables, medicines, food, transport, and waste. The results are therefore expressed as service-unit equivalents rather than as directly observed reductions in total health-system emissions. Where the clinical and environmental evidence referred to different populations or care pathways, the estimate was treated as an illustrative proxy and the limitation was stated explicitly.

3 Results

The available evidence supported four scenario pathways. Hospitalization provided the most direct pairing between an exercise-related utilization estimate and an empirically measured environmental footprint. The outpatient, diabetes, and cardiovascular pathways required progressively stronger assumptions about the type of care avoided and the transferability of international carbon factors (Table 1).

3.1 Hospitalization

Wright et al. [9] reported that participation in a community-based exercise program among older adults was associated with reduced all-cause hospitalization. In this retrospective longitudinal study involving 718 individuals, those participated in the exercise program for at least three months were compared with those who did not. Sustained participation was associated with 46% reduction in hospitalization risk (HR = 0.54, 95% CI [0.34, 0.87], p =0.01).

Acute care unit generates approximately 45 kg CO_2-e and 5.5 kg solid waste per hospitalization day [10]. Meanwhile, ICU generates 138 kg CO_2-e and 7.1 kg solid waste per bed-day [10]. Applying the reduction to the carbon conversion, the avoided carbon footprint was estimated to be 20.7 kg CO_2-e and 2.53 kg solid waste per day for regular inpatient care, and 63.48 kg CO_2-e and 3.27 kg solid waste per ICU bed-day.

3.2 Acute Outpatient or Emergency-Type Utilization

Evidence for outpatient care was less specific. Brar et al. [11] reported that membership in a medical fitness facility among older adults was associated with lower mortality, healthcare utilization, and cardiovascular events. Membership was associated with 13-23% lower risk for emergency department visit [11]. However, this finding cannot be interpreted as a reduction in all outpatient contact. Regular exercise may reduce unplanned or emergency-type encounters while increasing appropriate preventive visits, monitoring, or routine follow-up.

An England NHS study estimated that acute outpatient appointment generates approximately 76 kg CO_2-e per encounter [4], [12]. Applying risk reduction from Brar et al. [11], 9.88–17.48 kg CO_2-e was avoided per encounter. Among older adults, exercise reduced 46% all-cause hospitalization [9]. Hospitalization is reported to generate approximately 45 kg CO_2 and 5.5 kg solid waste per hospitalization day, and 138 kg CO_2 and 7.1 kg solid waste per bed-day in the intensive care unit [10]. Thus, the avoided carbon print was estimated to be 20.7 kg CO_2 and 2.53 kg solid waste per hospitalization-day. Meanwhile, the ICU scenario estimate avoided 63.48 kg CO_2 and 3.27 kg solid waste per bed-day.

3.3 Type 2 Diabetes

The Diabetes Prevention Program Research Group reported 58% reduction of type 2 diabetes incidence through intensive lifestyle intervention among high-risk adults [13]. However, the intervention included physical activity, dietary modification, and weight-loss targets. Therefore, this estimate is not indicating an exercise-only effect.

Type 2 diabetes generates approximately 144-155 kg CO_2-e per patient-year, for good and poor management, respectively [14]. Applying the 58% reduction scenario to the annual diabetes-care footprint gives an estimation of 83.52 kg CO_2-e per patient-year equivalent.

3.4 Cardiovascular Disease

For cardiovascular disease, Brar et al. [11] reported that medical fitness facility membership was associated with lower major adverse cardiovascular events among older adults. The estimated carbon footprint of acute decompensated heart failure care was approximately 263 kg CO_2-e per case and 32 kg CO_2-e per bed-day [15]. Applying a 28% lower cardiovascular event scenario gives 73.64 kg CO_2-e per cardiovascular case equivalent. Using the bed-day estimate, the avoided burden was 8.96 kg CO_2-e per bed-day.

No disease-specific waste factor was identified for diabetes or cardiovascular care. If the general acute inpatient waste factor from Prasad et al. [10] is used as a proxy, the 28% cardiovascular scenario corresponds to 1.54 kg of solid waste per inpatient bed-day equivalent. This is a weak proxy because cardiovascular diagnoses differ substantially in treatment intensity, length of stay, procedures, and material use.

Table 1. Scenario-Based Estimation Summary

Pathway	Reduction scenario	Carbon/waste factor	Estimated avoided burden
All-cause hospitalization	46% lower hospitalization risk	45 kg CO_2-e per acute hospitalization day	20.7 kg CO_2-e
All-cause hospitalization waste	46% lower hospitalization risk	5.5 kg waste per acute hospitalization day	2.53 kg waste
ICU upper-bound scenario	46% lower hospitalization risk	138 kg CO_2-e per ICU bed-day	63.48 kg CO_2-e
ICU waste upper-bound scenario	46% lower hospitalization risk	7.1 kg waste per ICU bed-day	3.27 kg waste
Acute outpatient / emergency-type encounter	13% reduction scenario	76 kg CO_2-e per encounter	9.88 kg CO_2-e
Acute outpatient / emergency-type encounter	23% reduction scenario	76 kg CO_2-e per encounter	17.48 kg CO_2-e
Type 2 diabetes mellitus	58% lower incidence	144 kg CO_2-e per patient-year	83.52 kg CO_2-e
Type 2 diabetes mellitus, 100-case scenario	58 prevented cases per 100 expected cases	144 kg CO_2-e per patient-year	8,352 kg CO_2-e/year
Cardiovascular disease / heart-failure proxy	28% lower event scenario	263 kg CO_2-e per case	73.64 kg CO_2-e
Cardiovascular inpatient bed-day proxy	28% lower event scenario	32 kg CO_2-e per bed-day	8.96 kg CO_2-e
Cardiovascular inpatient waste proxy	28% lower event scenario	5.5 kg waste per acute bed-day	1.54 kg waste

4 Discussion

The findings indicate that health promotion, particularly exercise, may have environmental co-benefits when it prevents avoidable healthcare utilization. The strongest evidence comes from the hospitalization risk reduction. A community-based exercise program was associated with a 46% reduction in hospitalization risk among older adults [9]. Using direct carbon and waste estimate by Prasad et al. [10], a potential reduction of 20.7 kg CO_2 and 2.53 kg solid waste per bed-day was demonstrated [9], [10].

The reduction of carbon footprint from outpatient service should be interpreted more conservatively. Despite the reduction of emergency visit due to exercise programs,

there may also an increase for preventive care, routine visits, or monitoring. Therefore, the appropriate interpretation is that exercise may reduce avoidable acute outpatient or emergency-type utilization, while potentially increasing preventive contact with health services. Therefore, green healthcare should mean reducing preventable, avoidable, low-value, or complication-driven care, instead of all necessary care.

The diabetes scenario provides a strong prevention reasoning but less direct estimate for exercise. The Diabetes Prevention Program showed that intensive lifestyle intervention reduced 58% incidence of type 2 DM. However, the intervention included diet and weight loss in addition to physical activity [13]. Therefore, this estimate is not a pure exercise scenario. Still, it is relevant to senam lansia because community-based physical activity can be part of the lifestyle modification for DM prevention. Applying this reduction to a diabetes-care footprint of 144 kg CO_2-e per patient-year suggests that preventing diabetes may generate substantial environmental benefits [14].

The potential environmental co-benefit of exercise in cardiovascular event is also promising but requires careful interpretation. Medical fitness participation has been associated with lower major adverse cardiovascular events, and heart-failure pathway studies show that cardiovascular hospital care has measurable carbon intensity [11], [15]. However, using acute decompensated heart failure as a proxy for cardiovascular disease is imperfect as CVS may present in various cases, including myocardial infarction, stroke, arrhythmia, heart failure, and hypertension complications. Each has different care pathways, length of stay, diagnostic procedures, medication patterns, and carbon footprints. Therefore, the finding should be presented as an illustrative proxy, not as a universal carbon reduction estimate for CVD.

Applying this scenario-based estimation for population in Indonesia is crucial for public health strategy. Senam lansia should not be considered merely as an exercise or social activity for older adults. It can play a crucial role as a preventive intervention with possible environmental co-benefits. This viewpoint is especially relevant because Indonesia does not yet have robust local carbon footprint factors for primary care visits, outpatient visits, hospital admissions, diabetes care, or cardiovascular care. Until those factors are available, any estimate must be treated as scenario-based and adapted from international data.

The biggest methodological weakness is the assumption of proportionality. A 46% reduction in hospitalization risk does not mean a 46% reduction in hospital carbon emissions. Fixed emissions from building energy, staffing, and infrastructure are not affected by use reduction. Moreover, emissions from consumables, food, waste, medications, and patient throughput are more variable. Therefore, the estimates in this paper should be interpreted as potential avoided environmental burden, not as directly measured health-system decarbonization.

Future study should measure local datasets to provide stronger evidence, particularly in Indonesia. The data include participation and adherence to senam lansia, healthcare utilization outcomes among older adults, and local carbon/waste factors for primary care, outpatient services, inpatient care, diabetes management, and cardiovascular care. Without those, the argument will remain plausible but not locally proven.

5 Conclusion

A scenario-based estimation suggests that exercise-related reductions in avoidable healthcare utilization may generate measurable environmental co-benefits. The strongest estimate was observed for hospitalization, where a 46% reduction in hospitalization risk applied to acute inpatient footprint data produced an estimated 20.7 kg CO_2-e and 2.53 kg solid waste avoided per hospitalization-day equivalent. Diabetes and cardiovascular disease scenarios also suggest potential carbon savings, but these estimates are more indirect and depend on assumptions about disease prevention, care pathways, and transferability of international carbon factors to Indonesia. Therefore, community-based elderly exercise may be positioned as part of a green health promotion strategy, but local Indonesian carbon accounting is needed before policy-level claims can be made.

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