






Review

Building Climate-Resilient Healthcare Systems by Engaging Adolescents in Sustainability Efforts

Sunjoo Kang ^{1,*}, Yeun Soo Yang ², Brita Mauritzen Naess ³, Da Sol Jung ¹ and Yeonsoo Jang ⁴

¹ Department of Global Health and Disease Control, Graduate School of Public Health, Yonsei University, Seoul 03722, Republic of Korea

² Department of Epidemiology and Health Promotion, Graduate School of Public Health, Yonsei University, Seoul 03722, Republic of Korea

³ Western Norway Regional Health Authority, 4068 Stavanger, Norway

⁴ Department of Nursing, College of Nursing, Yonsei University, Seoul 03722, Republic of Korea

* Correspondence: ksj5139@yuhs.ac

Abstract

Background: Climate change increasingly threatens global health, with adolescents among the most vulnerable. Hospitals are major emitters of greenhouse gases, making carbon reduction in healthcare a pressing challenge. Nurses play central roles in implementing sustainability, while adolescents can contribute to long-term resilience. **Methods:** A scoping review of peer-reviewed articles (1990–2023) and World Bank datasets was conducted. Comparative analysis focused on Norway and South Korea, with the United States and Australia reviewed narratively. Inclusion criteria targeted studies on hospital-based carbon reduction and youth/nurse engagement; unrelated studies were excluded. **Results:** Three domains emerged: (1) governance approaches—Norway applied top-down integrated monitoring, while Korea showed fragmented progress, especially in private hospitals; (2) roles of adolescents and nurses—nurses led quality improvement in energy efficiency and waste reduction, while adolescents contributed through school–hospital partnerships and youth initiatives; and (3) barriers and enablers—key barriers included limited youth decision-making and lack of councils, while enablers included certification frameworks and WHO guidelines. **Conclusions:** Nurses and adolescents are complementary partners in sustainable healthcare. Establishing hospital green teams, integrating climate literacy into curricula, and fostering government–healthcare–education partnerships can reduce emissions and strengthen climate-resilient health systems.

Keywords: adolescent; climate change; healthcare sustainability; carbon neutrality; environment awareness



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1. Introduction

Climate change is recognized as the most pressing global challenge, significantly affecting health and healthcare systems worldwide. Extremely hot and cold weather and also the natural disasters caused by global warming exacerbate health issues such as emerging infectious disease outbreaks, heat-related illnesses, and malnutrition, placing immense pressure on healthcare systems to respond effectively [1,2]. The healthcare area is responsible for 4.4–5.2% of global greenhouse gas (GHG) emissions, a level which is comparable to the 2–5% emitted by the aviation industry [3–5]. Hospital-based emissions not only contribute to environmental burdens but are also linked to adverse maternal health outcomes, including preterm births and low birth weights, due to air pollution

intensified by climate change [6]. Mitigating global warming through carbon emission reductions aligns directly with the United Nations' Sustainable Development Goals (SDGs), specifically in promoting health equity with environmental sustainability [7,8].

The Intergovernmental Panel on Climate Change (IPCC) identifies human activities, particularly fossil fuel consumption, as major accelerators of global warming, and underscores the urgent need for carbon-reduction strategies [2–7]. In response, healthcare systems worldwide are currently developing and implementing initiatives to minimize their carbon footprints [3,7,9–12]. Frameworks such as the European Union's Green Deal and the WHO's Climate-Smart Healthcare Initiative establish carbon neutrality goals and provide actionable methodologies for hospitals to achieve sustainability [13,14].

GHG emissions within healthcare systems are categorized into three categories: Scope 1, direct emissions from hospital operations; Scope 2, indirect emissions from energy consumption; and Scope 3, emissions from supply chains [15]. The Paris Agreement outlines a global aim to achieve near-zero healthcare emissions by 2050, necessitating decarbonization pathways that balance economic growth and healthcare spending. These pathways vary depending on the income levels and existing emission rates. Norway, Germany, and Sweden are expected to achieve steep declines by reducing their already high emissions, while Brazil, China, and South Africa aim for a steadier decline, balancing healthcare-system expansion with decarbonization efforts. Vietnam, Kenya, and Indonesia are projected to experience early peaks in emissions before implementing reductions, whereas low-income countries such as Uganda, Nigeria, and Bangladesh will adopt late-peak strategies, focusing on long-term decarbonization after achieving critical economic growth [15].

Despite growing interest in healthcare sustainability, there is a critical gap in the literature regarding the specific mechanisms and outcomes of adolescent and nurse engagement in hospital-based carbon neutrality initiatives. Existing research too often treats these groups as passive, failing to elucidate how their leadership and behavioral change can strengthen the adaptive capacity (resilience) of health systems or drive institution-wide transformation. This study directly addresses this gap by examining the strategic involvement of adolescents and nurses as active agents in building climate-resilient (adaptively robust) healthcare systems, and offers actionable recommendations for integrated, participatory sustainability policies.

Adolescents are increasingly recognized as important stakeholders in climate change adaptation and environmental health. Prior research indicates that their engagement is shaped by key behavioral factors such as risk perception, social norms, and a sense of efficacy [16–19]. For instance, family-based communication significantly influences adolescents' attitudes and willingness to act on climate issues [16], while school–community partnerships and local initiatives provide critical entry points for youth engagement in sustainability [17]. Recent studies emphasize that adolescents are not merely passive recipients of healthcare but active stakeholders in climate resilience. In China, adolescents with higher levels of climate knowledge and environmental responsibility were significantly more willing to engage in carbon neutrality education and adopt low-carbon behaviors [18]. Similarly, research from Ethiopia shows that adolescents view health literacy as behavioral responsibility, with potential to influence peers and communities [19]. These findings suggest that adolescents' agency is not limited to community or educational settings but can also extend into hospital-based sustainability initiatives, where their participation may enhance long-term effectiveness and foster intergenerational change. As climate change increasingly threatens adolescent health and well-being, their involvement in climate-smart (adaptive resilient) healthcare strategies has become essential [20]. Recent empirical studies based on behavioral science frameworks—such as the value–belief–norm (VBN) theory in Ghana [21] and the Theory of Planned Behavior (TPB) in China [22]—further demonstrate

that adolescents' pro-environmental actions are strongly influenced by their perceived values, normative beliefs, and behavioral intentions in diverse cultural contexts.

Nurses are central to achieving carbon reduction in hospitals because their roles integrate sustainability goals with patient safety and hospital operations [1–7,23,24]. Despite increasing attention in regard to climate change and planetary health, discussions surrounding practical, nurse-led interventions within clinical settings remain insufficient [1,7,23–27]. This study examines global examples of the contributions of nurses to carbon footprint reduction, with a particular emphasis on Norway's hospital initiatives, to demonstrate effective practices. Additionally, it explores strategies for strengthening the roles of nurses to achieve similar outcomes in South Korean hospitals, where sustainability efforts remain fragmented and underdeveloped.

While hospital-based carbon reduction has traditionally focused on clinical systems and healthcare professionals, it is equally vital to recognize the role of healthcare consumers in this transition—especially adolescents. As emerging health service users and future decision-makers, adolescents are uniquely positioned to support sustainable healthcare. Climate education, awareness of hospital-based emissions, and patient-side behaviors such as medication waste reduction, sustainable transport choices, and informed medical product use can collectively reinforce institutional carbon-neutral efforts. Integrating youth perspectives into hospital sustainability strategies can support long-term decarbonization goals.

2. Methods

2.1. Study Design

We carried out a scoping review of peer-reviewed articles and institutional reports focusing on hospital-based carbon reduction and youth/nurse engagement in sustainability, published in English from 1990 to 2023. Relevant literature was identified via PubMed, Embase, and Google Scholar.

For quantitative analysis, open-access macro-level datasets on key indicators—including CO₂ emissions, health expenditure, hospital beds, and renewable energy use—were retrieved from the World Bank database and subjected to descriptive, correlation, and regression analyses. Policy frameworks and case practices from Norway, and the Republic of Korea were comparatively summarized in structured tables and figures focusing on intervention design and implementation context. Country selection was restricted to Norway and Korea due to the availability of consistent open-access macro-level datasets and detailed institutional policy documents, and because these countries represent advanced healthcare systems with distinct governance approaches, providing meaningful grounds for comparative analysis. These cases provided sufficient depth for comparative synthesis, while other countries are referenced narratively where relevant but were not subjected to structured analysis.

2.2. Data Collection

Articles were retrieved from PubMed, Embase, and Google Scholar using the search terms: “climate change”, “climate resilience”, “carbon reduction”, “carbon neutrality”, “healthcare literacy”, “adolescent(s)”, “healthcare personnel”, and “carbon dioxide policy”. In addition, relevant data were collected from the World Bank database. The inclusion criteria were restricted to English-language documents published between 1990 and 2023, with explicit focus on hospital-based sustainability and adolescent/nurse engagement. Excluded were articles unrelated to healthcare or lacking direct relevance to sustainability.

2.3. Data Analysis

A narrative synthesis approach was used, organizing national cases and policy frameworks under major thematic headings. Quantitative trends and inter-variable relationships were visualized using time-series graphs, correlation matrices, and regression outputs based on World Bank data for Korea and Norway. All findings were triangulated and interpreted in relation to international (WHO, EU) benchmarks to identify practice gaps, policy enablers, and transferable lessons [13,28]. The study did not employ qualitative coding, NVivo, or direct interview-based methods.

3. Results

The results are organized into three major themes: (1) top-down versus bottom-up sustainability governance, (2) roles and models of youth/nurse participation, and (3) practical barriers and enablers of decarbonization. Illustrative quotations or case vignettes are provided for each theme.

In Norway, nurse-led QI teams spearheaded the switch to low-carbon anesthetic gases, stating, “Our leadership was key to winning institutional support”. In Australia, one hospital enabled youth advisory groups to co-design poster campaigns on sustainable behaviors, leading to measurable waste reduction [29,30].

3.1. Governance Approaches: Top-Down vs. Bottom-Up

This theme highlights how national governance structures influence hospital-based carbon reduction. Norway illustrates a strong top-down approach with government-led platforms and integrated monitoring, while Korea demonstrates more fragmented governance, with limited private sector engagement despite public sector policies.

The United Kingdom, through the NHS, actively implements carbon-reduction initiatives, emphasizing sustainability-driven Quality Improvement (QI) programs. Nurses play a pivotal role in achieving sustainable healthcare, particularly in regard to leadership and education [31]. For instance, the East London NHS Foundation Trust achieved significant reductions between 2022 and 2023, including a 37% decrease in direct GHG emissions and a 14% reduction in CO₂ emissions. Specific initiatives included educating patients to utilize reusable utensils, reducing monthly costs by 54% (from £173 to £79.5), improving medication request processes, which reduced pharmaceutical waste by 95% (equivalent to 66.2 kg CO₂ annually), and recycling rehabilitation aids, resulting in the return of 341 devices and saving 10,798 kg of CO₂ [31].

Healthcare Without Harm (HCWH), which originated in Europe and is now a global initiative, focuses on monitoring hospital emissions, enhancing energy efficiency, and reducing medical waste to promote health equity. Programs such as CleanMed Europe have fostered awareness and practical changes in hospitals. Nurses contribute to these efforts by proposing and implementing environmental policies, particularly waste management and resource conservation [24,31].

Norway, aligned with the EU Green Deal and the WHO’s carbon neutrality goals, has established a roadmap to obtain *Net Zero* emissions in the healthcare sector by 2045 [32,33]. This strategy systematically manages Scope 1, Scope 2, and Scope 3 while monitoring annual reductions through dedicated platforms [33,34]. Norwegian hospitals actively adopt renewable energy sources and low-carbon technologies. For example, Kirkenes Sykehus reduced energy consumption by 40% through geothermal and solar power, whereas the Trondheim Hospital utilized drones for biological sample transport, achieving cost savings and 95% lower emissions than conventional vehicles [11,29,34,35]. At Oslo University Hospital, nurses advocated replacing high-emission disposable syringes and needle containers (2 kg CO₂ per unit) with alternatives that emitted only 600 g of CO₂. Similarly,

low-carbon alternatives for disposable gloves and carbon absorption devices under anesthesia have been implemented, showing sustainability improvements along with operational efficiency [30].

Norway emphasizes measurement as a prerequisite for improvement. Scope 1 emissions encompass all direct GHG emissions controlled by hospital activities, including boilers, vehicles, and chemical processes, whereas Scope 2 tracks the carbon dioxide emissions from purchased energy for heating, cooling, and electricity. Although Scope 3 emissions arising from external supply chain activities are harder to quantify, they have been redefined through expert consultations to include the entire lifecycle of products, logistics, and waste processing [11]. Hospitals now require suppliers to document Scope 1 and 2 emissions and establish climate goals. Life Cycle Assessments (LCAs) further identify the major sources of indirect emissions, enabling targeted reductions [11].

The anesthesia sector represents a key opportunity for emission reduction. Anesthesia gas contributes approximately 5% of the GHG emissions in acute hospitals, whereas single-use surgical waste averages 2300 kg per operating room annually, with only 10% being recycled. Interviews with anesthesiologists and nurses highlighted barriers, such as excessive plastic packaging, which delay workflows and also generate significant waste [4].

3.2. Roles and Models of Adolescent and Nurse Participation

This theme emphasizes the complementary contributions of healthcare personnel and adolescents. In the United States and Australia, adolescents are increasingly involved through school–hospital partnerships and youth-led campaigns, while nurses lead clinical sustainability initiatives. In Korea, adolescent participation remains limited, yet nurses are beginning to drive energy efficiency and waste-reduction projects.

In the United States and Australia, hospitals have implemented both top-down and bottom-up sustainability strategies, with evidence of institutional benefits such as cost savings and health equity [3,5,33,36,37].

While U.S. initiatives are increasingly framed as an ethical obligation under the principle of “do no harm” [33], Australia has emphasized structured frameworks for resource efficiency and recycling. In addition, adolescent groups in Australia have co-designed hospital waste-reduction campaigns, promoting recycling and sustainable behaviors [36,37]. Importantly, both countries show emerging efforts to involve adolescents and families through education, school partnerships, and youth-led initiatives, highlighting the potential for intergenerational engagement [16,17].

3.3. Barriers and Enablers

This theme examines the structural and institutional factors that hinder or facilitate sustainability efforts. Barriers include limited adolescent decision-making power, lack of formal youth councils, and resource constraints. Conversely, enablers include international certification frameworks such as the Healthcare Sustainability Certification, government incentives, and alignment with WHO environmental sustainability guidelines [38].

South Korea has targeted carbon neutrality by 2050, as outlined in its first National Basic Plan, announced in 2023. This plan establishes phased emission-reduction goals for public healthcare institutions by mandating the use of low-carbon construction materials and renewable energy installations in newly constructed and renovated facilities. However, these policies have not yet been extended to private hospitals, resulting in a lack of systematic carbon emissions management and reduction activities across the sector [39,40].

While some individual hospitals have undertaken carbon-reduction initiatives, these efforts remain fragmented compared with the systematic approaches seen in the EU and Norway. For example, Samsung Medical Center has reduced its annual electricity consump-

tion by approximately 20% through the installation of high-efficiency LED lighting and power optimization systems [41]. Similarly, a general hospital pursued a green hospital certification and strengthened its medical waste management, achieving a 15% reduction in waste generation [42]. In renewable energy adoption, the other hospital installed rooftop solar power systems that produce 100,000 kWh annually, which is utilized in hospital operations [43]. Another hospital in Busan has also contributed to waste reduction by enhancing food waste management and waste segregation processes, resulting in cost savings for disposal [44]. Despite these efforts, the absence of comprehensive government support and any standardized guidelines has limited its broader implementation across South Korea's healthcare sector.

The IPCC's Sixth Assessment Report highlights three essential mitigation strategies to address environmental challenges: energy efficiency improvements, waste management and circular economy adoption, and low-carbon procurement policies. Energy efficiency involves the upgrading of hospital systems for heating, cooling, lighting, and medical equipment to reduce energy consumption. Waste management focuses on minimizing the use of single-use medical devices, transitioning to reusable equipment, and enhancing digitalization through the adoption of paperless hospitals using Electronic Medical Records (EMRs). Low-carbon procurement emphasizes prioritizing medical equipment and supplies with lower carbon footprints as well as sourcing local produce to reduce emissions from logistics and transportation.

Based on World Bank data, Figure 1 illustrates the trends in per capita CO₂ emissions between 1990 and 2022 for South Korea and Norway [28]. The comparison between the two reveals notable differences in the effectiveness of carbon-neutral policies within the healthcare sector. While Norway has achieved consistent reductions through top-down government-led policies and an integrated carbon-reduction platform, South Korea continues to face challenges due to the limited involvement of private hospitals. In Norway, nurse-led initiatives substituted high-emission anesthetics with lower-emission alternatives, directly reducing hospital carbon footprints. Addressing this gap requires a more comprehensive approach that integrates systematic carbon monitoring, standardized guidelines, and active participation from all healthcare stakeholders.

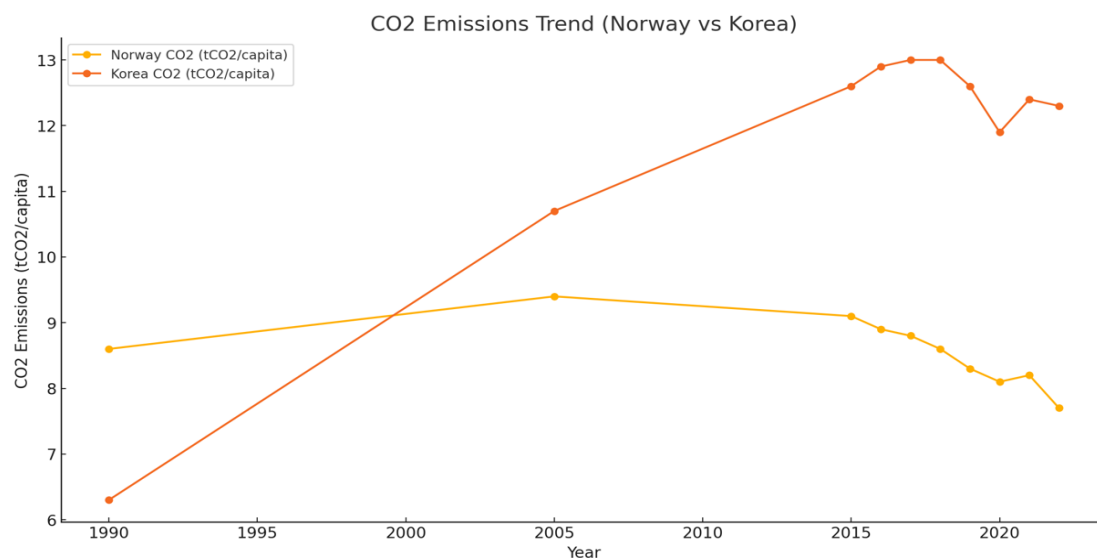


Figure 1. Trends in CO₂ emissions per capita: Republic of Korea vs. Norway (1990–2022). Note: This figure includes data only from Korea and Norway due to data availability and the scope of the quantitative analysis.

Figure 2 presents a correlation analysis between CO₂ emissions and key variables in South Korea, including renewable energy consumption by percentage of total final energy consumption, health expenditure per capita by current USD, hospital beds per 1000 people, renewable electricity output by percentage of total electricity output, and access to electricity by percentage of the population. The analysis indicated a strong positive correlation between the number of hospital beds and CO₂ emissions, suggesting that the expansion of healthcare infrastructure is closely linked to increased energy consumption [28].

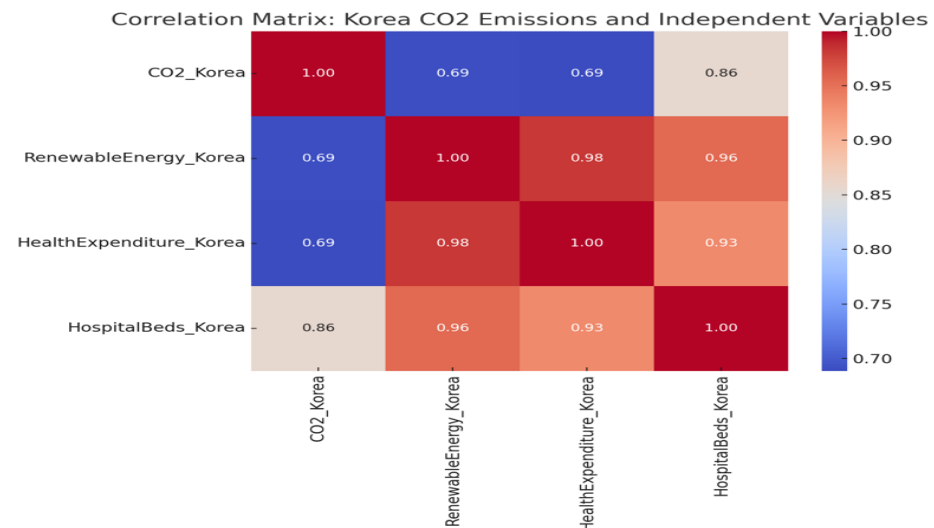


Figure 2. Correlation matrix of CO₂ emissions and related factors in the Republic of Korea. Note: This figure includes data only from Korea and Norway due to data availability and the scope of the quantitative analysis.

Figure 3 demonstrates the strong negative correlation between consumption and CO₂ emissions in Norway [28], highlighting the effectiveness of systematic carbon-reduction management strategies.

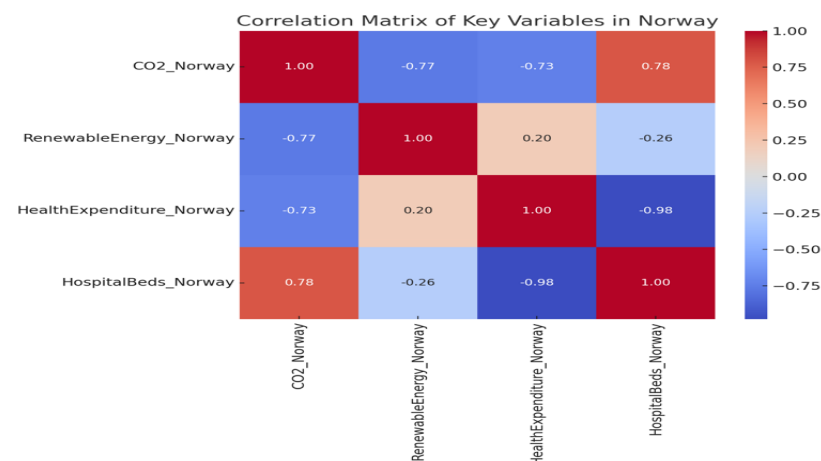


Figure 3. Correlation matrix of CO₂ emissions and related factors in Norway. Note: This figure includes data only from Korea and Norway due to data availability and the scope of the quantitative analysis.

Regression analysis was conducted to examine the impact of healthcare-related variables on CO₂ emissions, with CO₂ emissions as the dependent variable [40]. As shown in Table 1, the number of hospital beds had a significant positive effect on CO₂ emissions in South Korea. By contrast, in Norway, both the number of hospital beds and the proportion of renewable energy consumption were identified as key factors. These findings highlight

the differences in policy directions and carbon emissions management strategies between the healthcare sectors of the two countries.

Table 1. Regression analysis results for CO₂ emissions in Korea and Norway *.

	Republic of Korea		Norway	
	Coefficient	p-Value	Coefficient	p-Value
Intercept	7.123		17.523	
Renewable Energy	−1.994	0.086	−0.192	0.044
Health Expenditure	0.001	0.087	0.000	0.060
Hospital Beds	0.792	0.014	0.535	0.037

* Quantitative data were available only for these two countries.

While hospitals in South Korea are currently engaged in isolated activities, such as reducing food waste and improving energy efficiency, they lack a comprehensive platform for monitoring and systematically managing Scope 1, 2, and 3 emissions, as demonstrated in Norway. This gap highlights the need for nurses to adopt a bottom-up approach by recognizing the importance of carbon-reduction initiatives within hospitals. By expanding their roles to incorporate eco-competency and also the principles of planetary health and nursing, nurses can contribute significantly to fostering sustainable healthcare practices [25].

4. Discussion

In this study, engagement is conceptualized as a multidimensional process involving (1) knowledge acquisition, (2) participatory decision-making, and (3) adoption of climate-conscious behaviors within healthcare settings. This definition guided our interpretation of adolescent and nurse roles in hospital-based sustainability.

Expanding nurses' eco-competency and environmental literacy alongside strengthening adolescent engagement platforms can together drive progress toward sustainable healthcare. Comparative cases from Norway and Korea illustrate that while institutional initiatives reduce emissions, their long-term effectiveness depends on youth awareness and participation. However, adolescents currently face barriers such as limited decision-making power, the absence of institutionalized youth councils, and resource constraints, which together constrain their role as partners in sustainability [18,20]. Though hospitals in South Korea focus on reducing food waste and improving energy efficiency, healthcare personnel start to play a pivotal role in initiating bottom-up approaches to carbon reduction. In addition, adolescents—as emerging healthcare consumers—can reinforce institutional sustainability efforts by adopting climate-conscious behaviors and supporting low-carbon practices within healthcare settings. Despite these institutional efforts, adolescent involvement in hospital sustainability in Korea has not yet been systematically integrated. Establishing school–hospital collaborations and youth advisory platforms could help fill this gap and align Korea's healthcare sector with broader intergenerational approaches seen internationally.

First, healthcare personnel and adolescents must act as co-practitioners in promoting hospital sustainability. Nurses play a facilitation role in promoting sustainability through energy efficiency, waste reduction, and integration of environmental principles into daily practice. Rather than repeating functions across settings, their contribution is best understood as creating enabling environments where adolescents can participate meaningfully. [5,7,10,11]. By collaborating with youth through school–hospital partnerships, advisory councils, and climate literacy programs, nurses can extend their impact beyond clinical settings and intergenerational sustainability [16,18].

Second, healthcare personnel, along with healthcare consumers, must act as policy developers, lead efforts in resource management, design educational programs, and propose policies that can embed sustainability in hospitals [29,34]. By aligning their expanded roles with healthcare accreditation systems, such as Healthcare Sustainability Certification (HSC), nurses can effectively contribute to South Korea's carbon neutrality goals. International certification programs, such as the HSC, provide practical frameworks for carbon reduction and sustainable hospital operations, enabling nurses to guide hospitals toward tangible environmental outcomes [23,25]. To complement this, involving adolescents in hospital–community sustainability initiatives or school-linked health literacy programs can increase their capacity to act as future advocates and informed users of climate-smart health services [19].

Third, in collaboration with health experts, healthcare consumers, especially adolescents, should serve as leaders in understanding, educating, and disseminating global carbon-reduction standards. The WHO emphasizes the role of nurses in implementing frameworks for carbon reduction and environmental sustainability [4,14,28,44]. As end-users of medical resources, nurses can integrate operational efficiency, patient safety, and environmental protection into daily practice. This leadership involves managing projects at the ward level; engaging patients in sustainable behaviors, such as promoting the use of reusable materials, medication management, and medical equipment returns; and collaborating with multidisciplinary teams to achieve hospital-wide sustainability goals [1]. In this context, adolescents represent a strategic group to engage through education and participatory activities, enabling them to recognize their role in supporting hospital sustainability and shaping climate-resilient healthcare systems in the future [16,18,20].

Finally, healthcare decision-makers and their supporters must act as facilitators of change to drive institutional transformation. Key strategies include developing standardized improvement frameworks (e.g., “change packages”) to document and disseminate successful practices, establishing strong leadership to integrate sustainability into organizational culture, and providing systematic education to nurses and medical staff on environmental sustainability. Additionally, nurses can adopt data-driven approaches to monitor outcomes, assess progress, and refine carbon-reduction strategies. Partnering with adolescents—through social media outreach and youth-led campaigns—can amplify these strategies, promote shared ownership, and build a generation of health-conscious and environmentally aware healthcare users [16,18,20].

5. Conclusions

This study demonstrates that adolescents and nurses are important partners in advancing hospital-based sustainability and carbon reduction. Their complementary roles—nurses as facilitators of institutional change and adolescents as drivers of intergenerational engagement—provide a dual foundation for strengthening climate-resilient healthcare systems. Evidence from comparative cases suggests that institutional strategies must be coupled with education and participatory platforms to ensure long-term effectiveness.

Based on these findings, health policy makers should mandate the establishment of multidisciplinary green teams in hospitals; incorporate youth climate literacy and leadership modules into health curricula; promote structured youth advisory councils in hospital sustainability programs; and foster tripartite partnership among government, healthcare institutions, and education sectors.

Limitations include reliance on secondary data and published reports, and quantitative analysis limited to cases from two countries. In addition, the long-term outcomes of adolescent engagement were not assessed.

Future studies should include randomized or quasi-experimental designs to assess causality and sustainability, and should test replication across diverse healthcare and policy environments. Cross-national intervention trials and process evaluations of youth–nurse teams within hospitals are warranted to generate generalizable lessons and policy tools.

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