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Title:

Attitudes, Knowledge, Practices, and Perceived Barriers on Sustainability Actions Among Italian Anesthesiologists–Intensivists: A Nationwide Survey.

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Abstract

Background:

Healthcare systems contribute approximately 4.4% of global carbon emissions, with anesthesia and intensive care representing major sources of environmental impact. Although awareness of sustainable practices is increasing, real-world implementation in these fields remains limited. This study aimed to describe knowledge, attitudes, practices, and perceived barriers toward sustainability among Italian anesthesiologists–intensivists.

Methods:

A cross-sectional, web-based survey was conducted among members of the Italian Society of Anesthesia, Analgesia, Resuscitation, and Intensive Care (SIAARTI) between June and July 2025. The questionnaire assessed demographics, clinical practices, environmental behaviors, and perceived barriers to sustainability. Descriptive statistics and an unsupervised clustering approach (Factor Analysis of Mixed Data followed by hierarchical clustering) were applied to identify distinct respondent profiles.

Results:

A total of 459 responses were analyzed. Overall, 83.4% rated environmental sustainability as "very important," and 95.6% supported the adoption of renewable energy in hospitals. Despite this, 93.1% reported routine use of single-use devices, and only 7.4% worked in departments with a designated sustainability officer. Cluster analysis identified two main groups: the Experienced Generation (older, senior specialists) and the Green Generation (younger, early-career clinicians). While both valued sustainability, the Green Generation more frequently implemented eco-friendly practices, including the use of total intravenous anesthesia (71.2% vs. 57.5%), regional anesthesia (74.1% vs. 64.0%), and reusable/recyclable devices (>80% vs. <20%). The most frequently reported barriers to sustainability application were lack of training (76.3%), resistance to change (66.4%), and absence of guidelines (54.7%).

Conclusions:

Italian anesthesiologists–intensivists demonstrate strong environmental awareness but variable implementation of sustainable practices. Strengthening formal education, institutional leadership, and guideline dissemination is essential to promote widespread adoption of sustainable anesthesia and intensive care practices.

Keywords: sustainability, anesthesia, intensive care, environmental impact, green, SIAARTI, survey, Italy

Introduction:

Healthcare systems (HSs) provide essential services to populations but require extensive energy to operate accounting for approximately 4.6% of global carbon emissions, however systematic research into the extent of this contribution has only recently been initiated. (1,2)

As the environmental footprint of health systems (HSs) is projected to expand, the development and implementation of sector-specific decarbonization strategies must be prioritized, leveraging existing national and international policy frameworks. (3–5). In alignment with these global objectives, the Italian National Prevention Plan (Piano Nazionale della Prevenzione) identifies the healthcare sector as a pivotal stakeholder in both climate change mitigation and the strengthening of systemic resilience. (6) (https://www.salute.gov.it/new/sites/default/files/imported/C_17_pubblicazioni_2955_allegato.pdf).

While hospitals account for the largest proportion of total healthcare-related GHGs and solid waste(7), the provision of anesthesia and critical care medicine is particularly resource-intensive, contributing significantly to a facility's overall environmental footprint.(8).

While anesthesia care strategies are primarily dictated by surgical requirements and patient safety, clinical discretion increasingly accommodates environmental considerations. Although comprehensive global data are sparse, inhaled anesthetics are estimated to account for 0.01%–0.10% of total greenhouse gas (GHG) emissions and represent as much as 50% of the carbon footprint associated with perioperative services. (9). In this regards, desflurane was withdrawn from the NHS in Scotland in March 2023 (10) and subsequently from other countries (11,12) and its use has been recently banned in Europe except in cases where is medically necessary and no alternative anesthetic is suitable (https://www.europarl.europa.eu/doceo/document/A-9-2023-0048-AM-156-156_EN.pdf).

Beyond anesthetic gases, the environmental footprint of operating rooms and critical care units can be significantly reduced through the adoption of energy-efficient technologies, the integration of renewable energy sources, and enhanced waste management (13–15). For instance, heating, ventilation, and air-conditioning (HVAC) systems account for 90–99% of total energy use in operating rooms, and reducing their settings during unoccupied periods can safely achieve energy savings of up to 70% without compromising infection control or patient safety (16).

Recognizing that sustainable practices enhance patient safety and facilitate the delivery of high-value care (17), numerous national and international societies for anesthesia and intensive care have formally endorsed the integration of sustainability initiatives into clinical guidelines. (17–22).

In Italy, this commitment manifested through an expert panel of the Italian Society of Anesthesia, Analgesia, and Intensive Care (SIAARTI) which, under the 'Choosing Wisely' initiative, recently published two sets of clinical recommendations: one focusing on 'Green Anesthesia' and the other on mitigating inappropriate interventions in perioperative and intensive care. (23).

Despite a growing consensus on the benefits of sustainable practice, operational challenges such as safety concerns and workload continue to impede its integration into surgical and intensive care, necessitating a comprehensive approach focused on clinician education and the cultivation of a supportive organizational culture.(24–26).

We hypothesized that the implementation of sustainability practices among Italian anesthesiologists and intensivists is heterogeneous, influenced by organizational, cultural, and regional disparities inherent in a decentralized healthcare system.

To test this hypothesis, we conducted a national survey to assess knowledge, attitudes, and current practices, while identifying the key barriers, enablers, and institutional variations within this framework. (27).To our knowledge, this is the first national survey in anesthesia and intensive care to apply an unsupervised clustering approach to sustainability-related data. Traditional descriptive analyses capture mean tendencies but often overlook the complex, multidimensional patterns underlying clinicians' knowledge, attitudes, and behaviors. Our study identifies distinct professional subgroups with shared sustainability profiles, offering novel insight into how demographic, cultural, and organizational factors interact to shape ecological engagement in clinical practice.

Methods

Study Design, Setting, and Participant Recruitment

Since the study was non-interventional, it did not involve patients, patient data, vulnerable subjects, mood-related aspects or biological samples, formal Institutional Review Board (IRB) approval and pre-registration were deemed not applicable. Data integrity and the reliability of results were upheld in accordance with Good Clinical Practice (ICH E6(R3) standards(28). The study design precluded the collection of personal identifiers or sensitive data, thereby ensuring the permanent anonymity of all respondents in accordance with the General Data Protection Regulation (EU) 2016/679 (GDPR).The current report adheres to the Consensus-Based Checklist for Reporting of Survey Studies - CROSS reporting guideline(29). No specific inclusion or exclusion criteria were applied, as the survey was designed to capture a broad and comprehensive overview of sustainability practices among anesthesiologists and intensivists across Italian healthcare centers. Accordingly, the sample was considered a convenience sample, and the potential for internet coverage bias related to social media–based dissemination was acknowledged(30).

On June 1, 2025, an email invitation was sent to specialists and trainees affiliated with the Italian Society of Anesthesia, Analgesia, and Critical Care (SIAARTI). The invitation included a detailed description of:

- The study objectives.
- The voluntary nature of participation.
- The measures taken to ensure data confidentiality.

To maximize visibility and engagement regarding this time-sensitive topic, the survey link was also shared on official SIAARTI social media platforms (LinkedIn and X). Data collection concluded on July 30, 2025. To maximize participation, up to three reminder emails were dispatched at fifteen-day intervals. The survey was designed in *SurveyMonkey Platinum* (SurveyMonkey Inc., San Mateo, CA, USA), with responses automatically compiled into an online Excel dataset. No financial or material incentives were offered. To prevent duplicate entries, the survey required email-based validation ensuring one submission per respondent, with each participant subsequently assigned a unique, anonymous identifier. Crucially, these addresses remained decoupled from the survey

responses and were used solely for technical validation rather than identification.

Survey development

The survey instrument was developed using a rigorous, multi-step methodology. Between February and March 2025, a targeted literature search employing terms such as “survey,” “sustainability,” “anesthesia,” and “intensive care” identified no existing validated instruments suitable for this specific context. Consequently, a de novo survey was developed. Key conceptual domains were defined based on relevant guidelines and consensus documents(19–21,23)**.** Survey items were refined through a two-phase, iterative process involving discussion and consensus within a multidisciplinary working group of anesthesiologists and a statistician, ensuring content validity and feasibility:

1. **Pre-pilot Phase:** Seven members of the **SIAARTI** Sustainability and Inclusion Section and a senior statistician evaluated the instrument. This stage focused on assessing content relevance, linguistic clarity, and the completeness of the thematic domains.
2. **Formal Pilot Phase:** Following initial revisions, a formal pilot was conducted with a cohort of fifteen anesthesiologists, including experts from the SIAARTI Methodological and Research Section. This phase evaluated the instrument's technical feasibility, logistical flow, and average completion time to ensure it was optimized for final distribution.

The final questionnaire was organized into five distinct thematic sections:

- **Demographics and Professional Profile:** Included age, gender, professional experience, and work setting. Geographical distribution was categorized by Italian macro-regions:
    - **North:** Valle d’Aosta, Piedmont, Lombardy, Trentino–Alto Adige, Veneto, Friuli-Venezia Giulia, Liguria, and Emilia-Romagna.
    - **Center:** Tuscany, Umbria, Marche, and Lazio.
    - **South and Islands:** Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria, Sicily, and Sardinia.
- **Clinical Practice Patterns:** Assessed preferred anesthesia techniques, regional anesthesia utilization, monitoring habits, anesthetic gas selection, and device reuse/recycling behaviors.
- **Environmental Behaviors and Waste Management:** Evaluated recycling frequency (workplace vs. home), adoption of reusable medical devices, and strategies to reduce single-use materials.
- **Risk Perception and Attitudes:** Measured the importance attributed to environmental sustainability, concerns regarding plastic waste, and the perceived balance between patient safety and ecological impact.
- **Barriers to Sustainability:** Identified institutional, infrastructural, cultural, and knowledge-related obstacles to implementing sustainable practices.

Questions included single-choice, multiple-choice, and Likert-scale formats to capture both categorical and ordinal data.

Statistical Analysis

Categorical variables were summarized as counts and percentages and compared between groups using Chi-squared or Fisher's exact tests. Continuous variables were summarized as medians with interquartile ranges and compared with Mann–Whitney U test.

To explore heterogeneity in sustainability-related knowledge, attitudes, and practices beyond conventional descriptive statistics, we implemented an unsupervised clustering approach to identify latent respondent profiles and reveal underlying behavioral patterns within the study population. The methodological approach to cluster identification is summarized in Figure S1. Given the presence of mixed data types (continuous, categorical, and ordinal), Factor Analysis of Mixed Data (FAMD) was applied, for handling ordinal variables without requiring arbitrary dichotomization (FAMD)(31) to reduce dimensionality while retaining both numerical and categorical survey variables. To identify distinct respondent profiles based on sustainability-related knowledge, attitudes, and behaviors, we applied a clustering procedure tailored for mixed data types. Variables included in the multivariate analysis were selected a priori to reflect sustainability-related knowledge, attitudes, and practices. Demographic variables were used only for cluster characterization and were not included in cluster construction. Variables with more than 60% missingness or near-zero variance were excluded prior to analysis.

The resulting principal component scores were used as inputs for a hierarchical clustering algorithm. The optimal number of clusters was selected using the silhouette method, which evaluates the consistency of assignments by comparing within-cluster cohesion and between-cluster separation. Hierarchical clustering on principal components was also performed, and a dendrogram was generated to visualize the similarity structure among respondents.

Clusters were then characterized by examining the distribution of demographic variables, workplace characteristics, sustainability-related behaviors, and attitudinal measures within each group. Differences between clusters were reported descriptively to facilitate clinical interpretation of the profiles (e.g., high-engagement sustainability adopters vs. low-engagement groups).

Comparisons between clusters were performed for descriptive and exploratory purposes to characterize the profiles emerging from the unsupervised clustering analysis. Given the hypothesis-generating nature of these analyses, no formal correction for multiple comparisons was applied, and p-values should be interpreted accordingly.

All data preprocessing, descriptive statistics, and multivariate analyses were performed in R(32) (version 4.5.2).

We used ChatGPT (GPT-5.1 Thinking, OpenAI) to improve the clarity and readability of the manuscript. The model was employed only for language editing; all scientific content, data interpretation, and conclusions are solely the responsibility of the authors.

Results

Demographic and professional characteristics.

A total of 459 anesthesiologists-intensivists physicians completed the survey, corresponding to a 94% completion rate among those who started the questionnaire (Fig. 1, Supplementary table 1,

Supplementary figure 2)

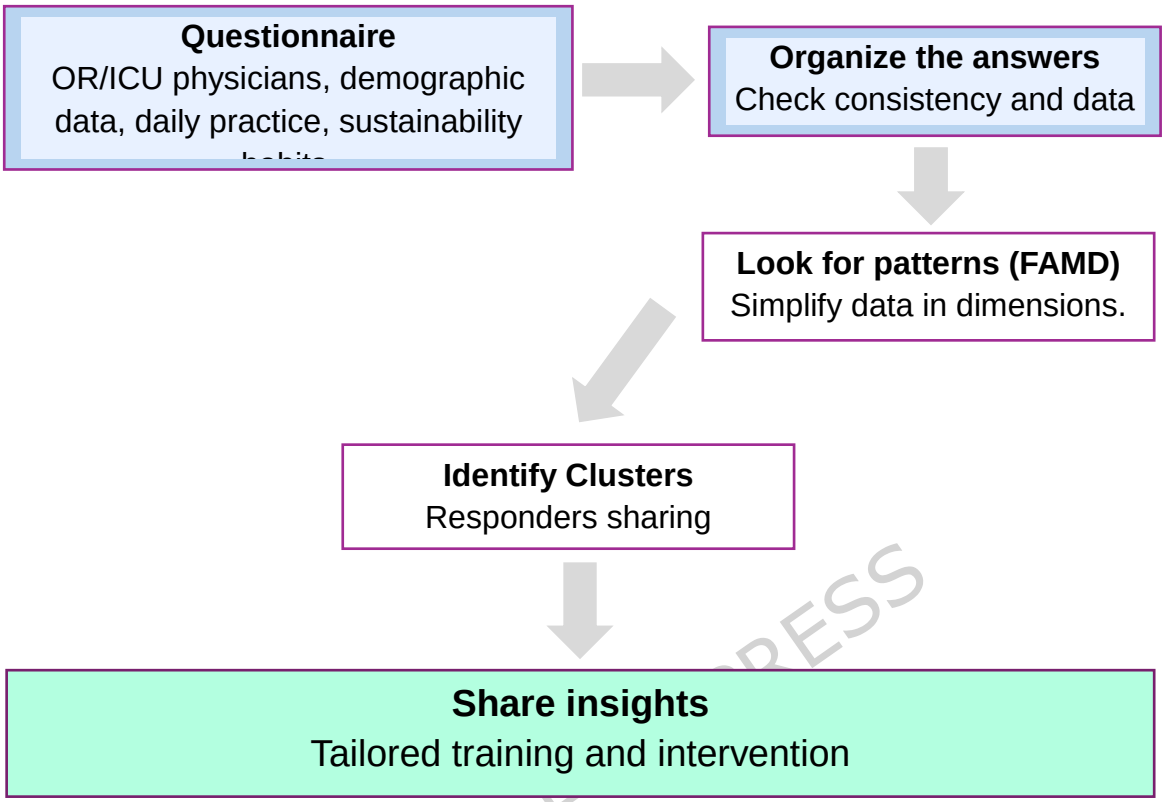


Figure 1. *Workflow of the OR and ICU (Operating room and Intensive Care Unit) Italian Anesthetists-Intensivists Sustainability Survey.*

A detailed analysis of missing data for each questionnaire item, including the count and percentage of non-responses, is provided in the **Supplementary Material (S4)**.

The process starts with questionnaire design and response collection, followed by data organization and cleaning. Responses are analyzed to identify patterns using Factor Analysis of Mixed Data (FAMD), leading to the detection of responder clusters with similar habits, and culminating in tailored insights for training and interventions.

The overall distribution of demographic and professional variables is shown in Figure 2A. Most respondents were female 61.4%, with males representing 38.6%. The median age was 42 years (IQR 33–51), with an age range from 26 to 67 years. In terms of geographic distribution 52.7% of respondents were based in Northern Italy, 30.5% in Central Italy, and 16.8% in Southern Italy.

In terms of work experience, 38.1% were senior specialists with over 15 years of practice, 26% were residents, 19% had 6–15 years of experience, and 17% were early-career specialists with 1–5 years of experience. Regarding institutional affiliation, the majority worked in university hospitals (51.2%), followed by public non-university hospitals (29.4%), private hospitals (8.7%), and other healthcare facilities (10.7%). The primary work setting was the operating room (76.7%), followed by intensive care units (18.5%), and other clinical areas (4.8%).

Only 7.4% reported having a sustainability officer within their department. Figure 2B presents the geographic distribution of respondents across Italian regions, highlighting greater participation from highly populated northern areas such as Lombardia, Veneto, and Emilia-Romagna.

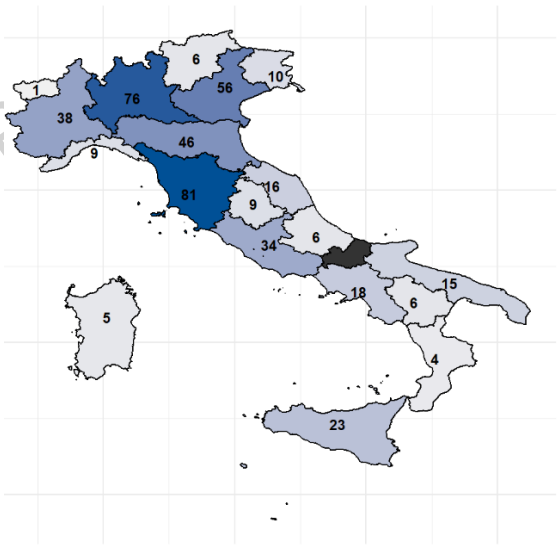
The proportion of missing data across survey variables was low (<20%), as illustrated in Supplementary Figure S2.

Figure 2. *Panel A:* Demographic and professional characteristics of the study sample (N=459), including gender distribution, age, geographical area, work experience, organization type, work setting, and presence of a sustainability officer.
Panel B: Geographic distribution of respondents across Italian regions, with shading intensity proportional to the number of participants.

Panel A Sample Description

	N=459
Gender:	
Female	282 (61.4%)
Male	177 (38.6%)
Age (years)	42.0 [33.0;51.0]
Area:	
North	242 (52.7%)
Center	140 (30.5%)
South	77 (16.8%)
Work Experience:	
Residents	119 (25.9%)
Early specialist 1–5 years	69 (15.0%)
Specialist 6–15 years	96 (20.9%)
Specialist > 15 years	175 (38.1%)
Organization:	
Public hospital	164 (35.7%)
University hospital	235 (51.2%)
Other type of healthcare facility	36 (7.84%)
Private hospital	24 (5.23%)
Work setting:	
Operating room / anesthesia	352 (76.7%)
Intensive care unit	82 (17.9%)
Other	25 (5.45%)
Sustainability officer present:	
No	425 (92.6%)
Yes	34 (7.41%)

Panel B Number of Responders by Italian Regions

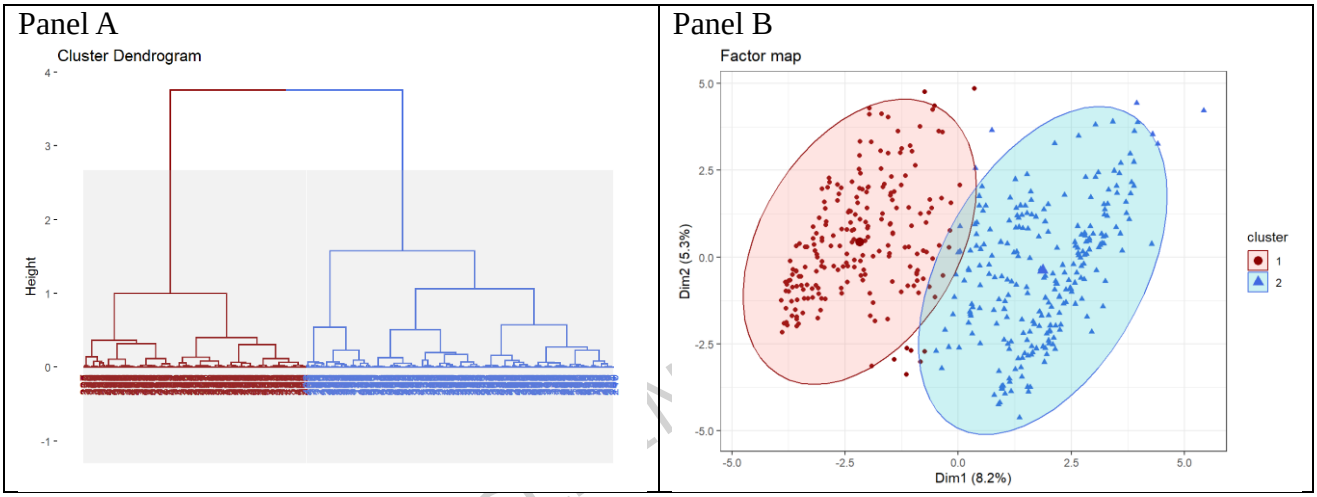


Cluster identification and visualization: K-means clustering was performed on the FAMD coordinates. The optimal number of clusters was determined using the silhouette method, which evaluates intra-cluster cohesion and inter-cluster separation; the highest silhouette coefficient was observed at k=2 (Supplementary Figure S3).

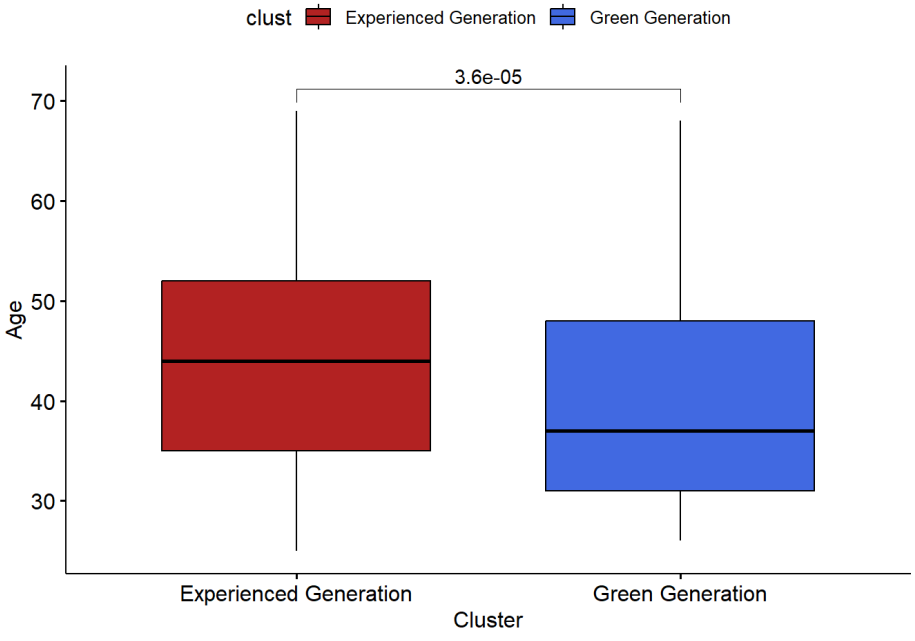
The analysis identified two distinct clusters. In Figure 3A, the hierarchical clustering dendrogram shows the separation between the two groups. The FAMD factor map (Figure 3B) confirms a clear separation in multidimensional space. Cluster sizes were balanced, with Cluster 1 comprising 49.7% of the respondents and Cluster 2 50.3%.

Age distribution differed significantly between clusters (Figure 3C). Cluster 1, hereafter referred to as the *"Experienced Generation"*, had a higher median age (44 years, IQR 37–53) compared to Cluster 2, the *"Green Generation"* (37 years, IQR 31–45; p<0.001).

Figure 3. *Clustering of Anesthesiologists-Intensivists physicians based on sustainability-related practices.*
Panel A: Hierarchical cluster dendrogram showing two distinct groups of responders.
Panel B: Factor map from Factor Analysis of Mixed Data (FAMD) illustrating separation of clusters in reduced dimensions.
Panel C: Age distribution across clusters, highlighting that the "Experienced Generation" (Cluster 1) is significantly older than the "Green Generation" (Cluster 2).



Panel C. *Age distribution across identified clusters. Boxplots show the median, interquartile range, and range of ages for the two clusters.*



Cluster characterization. The clustering analysis identified two distinct professional groups (Table 1): the *Experienced Generation* (Cluster 1, n=247) and the *Green Generation* (Cluster 2, n=212). Despite similar gender distributions (female: 63.2% vs. 59.4%, p=0.471), the groups differed significantly in age and professional seniority. The *Green Generation* had a higher proportion of residents (34.4% vs. 18.6%) and early-career specialists (17.0% vs. 13.4%). In contrast, the *Experienced Generation* was dominated by specialists with more than 15 years' experience (44.9% vs. 30.2%, p<0.001).

- **Shared values, different practices**. Both clusters overwhelmingly agreed that environmental sustainability is important (very important: 85.8% vs. 80.7%, p=0.174) and supported renewable energy adoption in hospitals (>95% in both groups). However, these shared values translated into diverse levels of practical engagement. The *Green Generation* showed greater adoption of environmentally friendly anesthesia techniques, with a higher preference for TIVA when appropriate (71.2% vs. 57.5%, p=0.003) and more frequent use of regional anesthesia (74.1% vs. 64.0%, p=0.026). They were also more likely to apply the principle of "regional when possible" (76.4% vs. 67.6%, p=0.047).
- **Devices and waste reduction.** A striking generational gap was observed in the knowledge and use of ecofriendly medical devices and a waste avoiding/reduction approach. The *Green Generation* reported markedly higher knowledge/use across all categories—ecofriendly plastic devices (89.6% vs. 15.0%), face masks/laryngeal masks (92.0% vs. 13.8%), appropriate avoiding/use of gowns/gloves (86.3% vs. 6.07%) and vascular access devices kit (81.6% vs. 2.02%)—with all comparisons yielding p<0.001. Almost all members of the *Green Generation* (99.5%) recognized at least one reusable/recyclable device in use, compared to only 40.9% of the *Experienced Generation*. Recycling behavior extended beyond the clinical setting: 99.1% of the *Green Generation* reported recycling both at home and in the hospital, compared to 92.7% of the *Experienced Generation* (p=0.002).
- **Emergency preparedness and sustainable choices.** Availability of pre-filled emergency syringes also differed. The *Green Generation* more often reported having atropine (54.7% vs. 40.1%, p=0.002), phenylephrine (34.9% vs. 23.9%, p=0.013), and ephedrine (38.2% vs. 27.9%, p=0.025) pre-filled syringes.
- **Perceived barriers**. Interestingly, the *Green Generation* was more likely to cite "resistance to change" or "lack of guidelines" as significant barriers.

Discussion

In this national survey of Italian anesthesiologists–intensivists, we observed a high level of awareness and positive attitudes toward environmental sustainability across all professional groups, moreover the unsupervised clustering approach based on sustainability-related practices identified two distinct profiles - an older, more senior "Experienced Generation" and a younger less experienced "Green Generation" - that shared similar values but differed substantially in practical engagement, adoption of eco-friendly clinical strategies, and perceived barriers to implementation.

Awareness, Knowledge, Practices, and Perceived Barriers to Sustainability Among Respondents

A substantial majority of respondents (83.4%) rated sustainability as very important, while an even higher proportion (95.6%) supported the integration of renewable energy sources into hospital

settings. These findings align with the World Health Organization's characterization of climate change as a global health threat(5,33) and with broader policy efforts to shift health systems from a linear to a circular economic model(24).

Moreover, Italian anesthesiologists-intensivists actively adopt several evidence-based practices to enhance environmental sustainability, such as opting for total intravenous anesthesia (TIVA) when appropriate (19), favoring regional anesthesia when feasible (19), minimizing nitrous oxide and desflurane choices when inhalational anesthesia is chosen (Sevoflurane 85.4%, Desflurane 13.9%, Isoflurane 0.4%, and Nitrous Oxide 0.2%), minimizing energy loss by keeping operating room doors closed during procedures and systematic waste segregation (20).

In contrast, awareness and implementation were markedly lower regarding the depth of anesthesia monitoring to optimize anesthetic consumption(34) and the limited adoption of gown-free protocols during regional anesthesia - despite SIAARTI guidelines discouraging their routine use(35). Similarly, lower rates were observed in the use of pre-filled syringes for emergency medications and the application of energy-saving strategies for intensive care equipment as recommended by the ESAIC Declaration of Glasgow(20).

Resource use practices showed a marked dependence on single-use materials (93.1%), nonetheless, almost two-thirds of respondents (62.3%) supported initiatives to reduce their consumption. This reliance reflects the institutionalized normalization of single-use plastics as the primary paradigm for infection prevention(36), contrasted against the emerging recognition of the environmental and public health risks associated with healthcare-generated microplastics(37). Even so, awareness of recyclable, reusable, or otherwise lower-impact device options was limited, with nearly one-third (32.0%) unable to identify any sustainable alternatives highlighting a critical requirement to prioritize evidence based comparative analysis between disposable and reusable devices(38) and increase the availability of safe biodegradable or reusable options in clinical practice(39).

When examining sustainability at the level of large organizations, regrettably, only 23% of respondents reported that companies incorporate sustainability into single-use devices or drugs, despite the need to promote the adoption of reusable products and improve recyclability. Similarly, just 7.4% of public hospitals reported having a designated sustainability officer, compared with 55% in Australia and New Zealand (40). These findings highlight the need for further investigation into corporate and hospital-level policies and strategies to advance sustainability.

Most respondents reported consistent adherence to waste segregation protocols in both domestic and clinical environments, however, similar to Brazilian colleagues (41), about one third indicated they were unable to do so at their workplace, and only a similar proportion had received formal training on the subject. In this context, the reported recycling rate of 65% represents a marked increase compared to prior international surveys of anesthesia providers, specifically outpacing data from Australia and New Zealand (11%), the United States (28%), and Canada (30%) (42–44).

The survey identified some barriers to advancing sustainability in anesthesia and intensive care including a lack of formal training, resistance to change, and the absence of clear institutional guidelines.

The deficiency in formal training has been repeatedly reported as an obstacle in several surveys on this topic (42,44–46). A recent study explicitly conducted among department chiefs in Canada (47),

revealed that, despite their interest in environmental sustainability, they identified a poor integration of sustainability into training pathways, as only 29% of responding Canadian anesthesiology programs include environmental sustainability in their curriculum.

Addressing the complex systemic inertia and individual resistance to sustainable anesthesia requires multimodal enabling strategies. Current approaches focus on stakeholder engagement and targeted pedagogical frameworks designed to illuminate the ecological footprint of perioperative care while providing evidence-based sustainable protocols(48,49). However, there is a critical need for implementation of science research to rigorously evaluate the longitudinal efficacy of these interventions in fostering durable behavioral and cultural shifts.

Lastly, although guidelines on sustainable practice in anesthesia and intensive care exist and are widely available across countries (17,19,20,23), survey responses reveal a significant lack of awareness and likely harmonization and dissemination of these guidelines.

Generational Differences in Sustainability: Green vs. Experienced Practitioners

The survey results delineate a significant cohort effect between early-career practitioners - designated as the “Green Generation” - and their senior counterparts, the “Experienced Generation”. The Green Generation demonstrated a significantly higher propensity for translating environmental values into clinical action, effectively narrowing the attitude-behavior gap observed in more senior clinicians. In particular, although the two clusters adopted similarly TIVA, balanced and general anesthesia, the Green Generation reported greater use of low-impact anesthetic techniques (TIVA, regional anesthesia)(50) when appropriate. Broader knowledge of ecofriendly devices (masks, breathing circuits, laryngoscope blades)(36,51–62), and near-universal engagement in recycling both at work and at home are other characteristics that aligned this cluster to sustainability.

The Green Generation also demonstrated higher availability/utilization of pre-filled emergency syringes as well as more frequent use of depth monitoring and total intravenous anesthesia. An intriguing finding is the bimodal distribution in the adoption rate of pre-filled syringes between the two professional cohorts, despite homogeneity in geographic provenance and institutional setting. This suggests a generational cleavage in the acceptance of sustainable practice changes, where the younger cohort demonstrates a higher propensity for integrating novel, environmentally conscious solutions than the senior generation, whose entrenched practices may be influenced by a stronger adherence to conventional methods, such as those historically associated with acute and emergency drug preparation which have already been associated with concerning levels of drug wastage (63).

Perceived barriers to sustainability, specifically resistance to change and a deficit in standardized environmental protocols, were more frequently identified by the Green Generation. This higher reporting frequency likely reflects an urgent imperative for the broader dissemination and cross-institutional harmonization of clinical sustainability guidelines. Comparable trends have been observed in Brazil, where residents reported recycling more frequently, expressed greater confidence in their environmental knowledge, invested more in sustainability education, and demonstrated greater awareness of the climate impact of hospital waste than senior anesthesiologists. The convergence of findings across two different healthcare systems could suggest that generational rather than cultural or geographic factors may be driving the alignment with sustainable practices (41).

Sample profile

The number of participants was adequate and consistent with that observed in similar surveys addressing this subject (41,43–45,64,65). The study cohort was predominantly female (>60%), a distribution that aligns with the shifting gender demographics of the anesthesia and intensive care workforce in Italy (66). This preponderance may also suggest a greater thematic engagement with environmental sustainability among female clinicians within the specialty (67). The median age of 42 years (IQR 33–51) reflects a balanced representation of both early- and mid-career professionals, while the overall age range (26–67 years) suggests that perspectives from different career stages were included. Nonetheless, professional profile of the 459 respondents suggests a selection bias, with high participation from residents (25.9%) and academic-based professionals. While this may not fully reflect the broader Italian anesthesiology community, it provides indirect insight into professional engagement levels. The identification of a significantly younger Green Generation (median age 37.0 vs. 44.0 in the Experienced group; $p < 0.001$) suggests that sustainability initiatives currently resonate more strongly with younger cohorts and those in academic settings. Conversely, the lower participation of older clinicians may signal a 'relevance gap' in certain practice environments. These findings highlight the need for targeted educational interventions to bridge this generational divide and foster a more universal commitment to sustainable healthcare.

Geographically, respondents were concentrated in Northern Italy, a region with a higher density of academic and tertiary referral centers. This distribution aligns with the prevalence of university-affiliated participants(68) and reflects regional disparities in both healthcare infrastructure and the implementation of decarbonization initiatives(69). Finally, with 76.7% of respondents practicing in the operating room and 18.5% in intensive care, these findings primarily represent perioperative perspectives, a domain characterized by high resource intensity and significant environmental impact.

Limitations and Strengths

This study provides the first description of Italian anesthesiologists' and intensivists' awareness, knowledge, practices, and perceived barriers regarding sustainability in anesthesia and intensive care, and it is the first publication within the SIAARTI Sustainability Section.

Several limitations should be considered when interpreting our findings. First, this study was not preregistered, which may limit transparency regarding the initial data analysis plan and the formal distinction between *a priori* and *post hoc* hypotheses. Second, the anonymous nature of the survey design precluded a formal non-response bias analysis; therefore, we cannot entirely exclude the possibility that respondents hold systematically different views on sustainability than non-participants. Moreover, to prioritize participant anonymity and data protection, institutional identifiers were not collected. Consequently, clustering by center could not be assessed, which may have led to over- or underestimation of certain practices if multiple respondents originated from the same institution, as all responses were treated as independent observations and should be interpreted as reflecting practitioners' perceptions rather than a census of institutional policies.As with other survey-based studies, the use of questionnaires may introduce methodological bias (70). In addition, because this was an exploratory analysis, p-values were not adjusted for multiplicity, and although inferential methods were used to examine associations within the study sample, these results should be interpreted as exploratory and hypothesis-generating rather than supporting causal or population-

level inferences. This approach prioritizes the identification of potential trends but requires that the reported associations be confirmed in future, pre-specified studies. Furthermore, the national, cross-sectional nature of study design may limit the global generalizability of the findings. The supplementary promotion via social media SIAARTI channels made it impossible to track the exact number of unique professionals who viewed the invitation. Consequently, a formal response rate cannot be precisely determined and can only be estimated against the total SIAARTI membership. While our sample size was sufficient for national estimates, these results should be considered a baseline for future multi-professional and longitudinal studies to further explore sustainability in healthcare.

Finally, this study focused exclusively on anesthesiologists and intensivists, excluding other essential stakeholders in perioperative and intensive care, such as nursing staff and hospital administrators.

Nonetheless, the cluster analysis provided a novel, data-driven understanding of demographic and professional variables, such as age, seniority, and workplace characteristics, shape sustainability-related knowledge, attitudes, and behaviors. By distinguishing these clusters, the study offered valuable insight for designing tailored educational programs and institutional interventions that can engage both senior clinicians, who may benefit from structured awareness and leadership initiatives, and younger anesthesiologists, whose higher environmental engagement could be leveraged to drive cultural change within departments.

Strategies to Enhance Ecological Literacy and Sustainable Clinical Integration

The survey results reveal a significant "operational gap": while 83.4% of respondents view environmental sustainability as a priority, actionable knowledge remains inconsistent. To bridge this divide, a multifaceted approach is required, targeting individual behavior, institutional culture, and industry partnerships.

1. Targeted Education and the Knowledge-to-Action Gap

Despite high general concern, only 30.5% of participants possess specific knowledge regarding the environmental impact of anesthetic gases. This highlights the necessity for targeted educational initiatives such as dedicated webinars and congress tracks focused on the carbon footprint of anesthetic agents. Educational efforts should emphasize that the choice of anesthetic technique is a primary determinant of a department's ecological footprint, necessitating a move toward low-carbon clinical pathways.

2. Dissemination and Implementation of Existing Guidelines

Interestingly, 54.7% of clinicians cite a "lack of guidelines" as a major barrier, despite the existence of robust frameworks such as the SIAARTI/Choosing Wisely Italy "Green" recommendations, the ESAIC guidelines, the Glasgow Declaration and the ESICM Green Paper. This discrepancy suggests a failure in active dissemination and local adaptation rather than a lack of literature. Future strategies must focus on the longitudinal implementation of these established guidelines into local

hospital protocols to overcome the "resistance to change" reported by 66.4% of respondents.

3. Supply Chain Literacy and Circular Economy

The heavy reliance on single-use devices (93.1%) underscores a critical need for supply chain transparency. Educational efforts must integrate Life Cycle Assessment (LCA) data to illustrate the hidden ecological costs of single-use plastics ranging from manufacturing emissions to microplastic pollution to foster a culture of mindful procurement and transition toward a circular healthcare economy.

4. Institutional Engagement and Policy Leadership

The near-total absence of Sustainability Officers (92.6%) highlights a void in medical leadership. Institutional engagement should move beyond individual goodwill toward the formal appointment of "Green Officers" within Anesthesia and ICU departments. These figures serve as vital links between clinical staff, “green” teams and hospital administration, ensuring that sustainability is integrated into the institutional mission and that clinicians are empowered to lead ecological reforms from a position of recognized authority.

5. Multidisciplinary Infrastructure, Energy, and Waste Management

Energy and waste management represent untapped opportunities for significant carbon reduction. Since only 5.6% of responders declared the utilization of energy-saving protocols in ICU equipment and 68.7% have received no formal waste training, two parallel actions are required:

- Energy Optimization: Collaborative efforts with hospital engineers are essential to manage high-energy systems, such as HVAC (Heating, Ventilation, and Air Conditioning) and air exchange rates in the OR during non-operative hours.

- Waste Stewardship: Implementation of rigorous waste-segregation protocols and educational workshops is needed to improve knowledge of waste streams. This will reduce the volume of clinical waste and prevent the improper disposal of hazardous materials, thereby lowering the carbon intensity of waste processing.

6. Sustainable Mobility and Digital Health Transition

Our data indicates a high reliance on private vehicle use for commuting (70.2%), representing a significant indirect (Scope 3) emission source. Institutions should promote sustainable mobility through carpooling incentives, improved cycling infrastructure, and subsidized public transport. Furthermore, where clinically appropriate, the expansion of telemedicine (currently supported by 68.6% of the sample) can drastically reduce the carbon footprint associated with patient travel and hospital admissions, aligning clinical efficiency with environmental goals.

7. Corporate Responsibility and Cradle-to-Grave Stewardship

With only 23.3% of clinicians receiving environmental data from industry, there is a clear mandate for enhanced corporate transparency. Beyond addressing drug wastage, companies must be held accountable for the entire cradle-to-grave carbon footprint of their products. This involves adopting sustainable device designs, utilizing low-impact materials, and providing comprehensive LCA data. Industry partners must move toward offering "green" procurement options that prioritize

recyclability and reduced packaging, empowering clinicians to make evidence-based, sustainable choices in their daily practice.

Conclusions

This nationwide survey demonstrates strong commitment to environmental sustainability among Italian anesthesiologists–intensivists yet reveals a persistent gap between awareness and clinical implementation. Deficits in education, guideline uptake, institutional leadership, and practice consistency hinder sustainable anesthesia and intensive care, highlighting the need for structured training, integrated sustainability frameworks, and formal institutional engagement.

Declarations

Human Ethics and Consent to Participate declarations: not applicable.

Clinical trial number: not applicable.

Consent for publication: Not applicable

Availability of data and materials

The data that support the findings of this study are available from SIAARTI, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of SIAARTI.

Competing interests

S. R. serves as an editor for the Journal of Anesthesia, Analgesia and Critical Care. He had no role in the editorial management, peer-review process, or final decision regarding this work. The other authors declare that they have no competing interests.

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Authors' contributions

S.S. R.M. G.C. conceptualized the study and drafted the initial manuscript version. D.A. analyzed the data and created tables and figures. All authors participated in the questionnaire production process, reviewed the manuscript, made edits, and approved the definitive version for submission.

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Table 1. *Comparison of demographic characteristics, risk perception, work environment, habits, lifestyle, and perceived barriers between two clusters of ICU physicians ("Experienced Generation" and "Green Generation").* Variables are reported as number (percentage) or median [IQR]; *p*-values are from χ^2 or Mann–Whitney U tests, as appropriate.

	Cluster 1	**Cluster 2**	**Overall sample**	
	Experienced Generation	**Green Generation**		**P Value**
	N=247	N=212	N=459	
Demographic Variables				
Gender				0.471
Female	156 (63.2%)	126 (59.4%)	282 (61.4%)	
Male	91 (36.8%)	86 (40.6%)	177 (38.6%)	
Age (Years)	44.0 [35.0;52.0]	37.0 [31.0;48.0]	42.0 [33.0;51.0]	**<0.001**
Area				0.578
North	125 (50.6%)	117 (55.2%)	242 (52.7%)	
Center	80 (32.4%)	60 (28.3%)	140 (30.5%)	
South	42 (17.0%)	35 (16.5%)	77 (16.8%)	
Work experience (years)				**<0.001**
Residents	46 (18.6%)	73 (34.4%)	119 (25.9%)	
Early specialist 1–5 years	33 (13.4%)	36 (17.0%)	69 (15.0%)	
Specialist 6–15 years	57 (23.1%)	39 (18.4%)	96 (20.9%)	
Specialist > 15 years	111 (44.9%)	64 (30.2%)	175 (38.1%)	
Risk Perception				
Importance of environmental sustainability				0.174
Very important	212 (85.8%)	171 (80.7%)	383 (83.4%)	
Slightly or moderately important	35 (14.2%)	41 (19.3%)	76 (16.6%)	
Hospitals should adopt renewable energy				1.000
No	11 (4.45%)	9 (4.25%)	20 (4.36%)	
Yes	236 (95.5%)	203 (95.8%)	439 (95.6%)	
Concern about plastics health risks				0.909
Extremely concerned	45 (18.8%)	39 (18.4%)	84 (18.6%)	
Moderately concerned	74 (31.0%)	69 (32.5%)	143 (31.7%)	
Very concerned	85 (35.6%)	76 (35.8%)	161 (35.7%)	
Not at all concerned	8 (3.35%)	4 (1.89%)	12 (2.66%)	
Slightly concerned	27 (11.3%)	24 (11.3%)	51 (11.3%)	
Concern about safety vs sustainability				0.378
No	196 (79.4%)	160 (75.5%)	356 (77.6%)	
Yes	51 (20.6%)	52 (24.5%)	103 (22.4%)	
Work Environnement				
Work Structure				0.857
Other types of healthcare facility	20 (8.10%)	16 (7.55%)	36 (7.84%)	
Private hospital	14 (5.67%)	10 (4.72%)	24 (5.23%)	
Public hospital	91 (36.8%)	73 (34.4%)	164 (35.7%)	
University hospital	122 (49.4%)	113 (53.3%)	235 (51.2%)	
Work setting				0.441
Other	12 (4.86%)	13 (6.13%)	25 (5.45%)	
Operating room / anesthesia	186 (75.3%)	166 (78.3%)	352 (76.7%)	

Intensive care unit	49 (19.8%)	33 (15.6%)	82 (17.9%)	
Sustainability officer present				0.086
No	234 (94.7%)	191 (90.1%)	425 (92.6%)	
Yes	13 (5.26%)	21 (9.91%)	34 (7.41%)	
Habits				
Which anesthesia technique do you use most frequently?				
Balanced anesthesia				0.569
Never / sometimes	96 (38.9%)	76 (35.8%)	172 (37.5%)	
Often / always	151 (61.1%)	136 (64.2%)	287 (62.5%)	
Total intravenous anesthesia (TIVA)				0.152
Never / sometimes	126 (51.0%)	93 (43.9%)	219 (47.7%)	
Often / always	121 (49.0%)	119 (56.1%)	240 (52.3%)	
Regional anesthesia				**0.026**
Never / sometimes	89 (36.0%)	55 (25.9%)	144 (31.4%)	
Often / always	158 (64.0%)	157 (74.1%)	315 (68.6%)	
Depth monitoring use				0.059
Never / sometimes	94 (38.1%)	62 (29.2%)	156 (34.0%)	
Often / always	153 (61.9%)	150 (70.8%)	303 (66.0%)	
Main anesthetic gas				1.000
Halogenated agents	246 (99.6%)	212 (100%)	458 (99.8%)	
Nitrous oxide	1 (0.40%)	0 (0.00%)	1 (0.22%)	
Knowledge of gas environmental impact				0.974
No	171 (69.2%)	148 (69.8%)	319 (69.5%)	
Yes	76 (30.8%)	64 (30.2%)	140 (30.5%)	
Prefer TIVA when appropriate				**0.003**
No	105 (42.5%)	61 (28.8%)	166 (36.2%)	
Yes	142 (57.5%)	151 (71.2%)	293 (63.8%)	
Avoid desflurane and nitrous oxide when possible				0.173
No	131 (53.0%)	98 (46.2%)	229 (49.9%)	
Yes	116 (47.0%)	114 (53.8%)	230 (50.1%)	
Reduce single-use materials				0.296
No	99 (40.1%)	74 (34.9%)	173 (37.7%)	
Yes	148 (59.9%)	138 (65.1%)	286 (62.3%)	
Use regional anesthesia when possible				**0.047**
No	80 (32.4%)	50 (23.6%)	130 (28.3%)	
Yes	167 (67.6%)	162 (76.4%)	329 (71.7%)	
No specific strategy				0.116
No	239 (96.8%)	210 (99.1%)	449 (97.8%)	
Yes	8 (3.24%)	2 (0.94%)	10 (2.18%)	
Gowns use in regional blocks				0.153
No	168 (68.0%)	158 (74.5%)	326 (71.0%)	
Yes	79 (32.0%)	54 (25.5%)	133 (29.0%)	
Telemedicine support				0.107
No	69 (27.9%)	75 (35.4%)	144 (31.4%)	
Yes	178 (72.1%)	137 (64.6%)	315 (68.6%)	
Are operating room doors closed during surgery?				0.179
Never / sometimes	40 (16.3%)	46 (21.7%)	86 (18.8%)	
Often / always	205 (83.7%)	166 (78.3%)	371 (81.2%)	
Use of energy saving in ICU equipment				1.000

No	233 (94.3%)	200 (94.3%)	433 (94.3%)	
Yes	14 (5.67%)	12 (5.66%)	26 (5.66%)	
Waste management training received				0.442
No	160 (66.9%)	150 (70.8%)	310 (68.7%)	
Yes	79 (33.1%)	62 (29.2%)	141 (31.3%)	
Segregated waste disposal				0.243
No	92 (37.2%)	67 (31.6%)	159 (34.6%)	
Yes	155 (62.8%)	145 (68.4%)	300 (65.4%)	
Frequency of single-use devices				0.689
Never / sometimes	18 (7.53%)	13 (6.13%)	31 (6.87%)	
Often / always	221 (92.5%)	199 (93.9%)	420 (93.1%)	
Knowledge/use of reusable/recyclable devices				
Plastic devices				**<0.001**
No	210 (85.0%)	22 (10.4%)	232 (50.5%)	
Yes	37 (15.0%)	190 (89.6%)	227 (49.5%)	
Face masks or laryngeal masks				**<0.001**
No	213 (86.2%)	17 (8.02%)	230 (50.1%)	
Yes	34 (13.8%)	195 (92.0%)	229 (49.9%)	
Drug containers				**<0.001**
No	213 (86.2%)	75 (35.4%)	288 (62.7%)	
Yes	34 (13.8%)	137 (64.6%)	171 (37.3%)	
Syringes				**<0.001**
No	238 (96.4%)	19 (8.96%)	257 (56.0%)	
Yes	9 (3.64%)	193 (91.0%)	202 (44.0%)	
Gowns or gloves				**<0.001**
No	232 (93.9%)	29 (13.7%)	261 (56.9%)	
Yes	15 (6.07%)	183 (86.3%)	198 (43.1%)	
Vascular access devices (VADs)/VADs kit				**<0.001**
No	242 (98.0%)	39 (18.4%)	281 (61.2%)	
Yes	5 (2.02%)	173 (81.6%)	178 (38.8%)	
Know none of the above devices				**<0.001**
No	101 (40.9%)	211 (99.5%)	312 (68.0%)	
Yes	146 (59.1%)	1 (0.47%)	147 (32.0%)	
Which of these pre-filled syringes for emergency medications do you have available?				
Atropine				**0.002**
No	148 (59.9%)	96 (45.3%)	244 (53.2%)	
Yes	99 (40.1%)	116 (54.7%)	215 (46.8%)	
Adrenaline				0.127
No	204 (82.6%)	162 (76.4%)	366 (79.7%)	
Yes	43 (17.4%)	50 (23.6%)	93 (20.3%)	
Phenylephrine				**0.013**
No	188 (76.1%)	138 (65.1%)	326 (71.0%)	
Yes	59 (23.9%)	74 (34.9%)	133 (29.0%)	
Ephedrine				**0.025**
No	178 (72.1%)	131 (61.8%)	309 (67.3%)	
Yes	69 (27.9%)	81 (38.2%)	150 (32.7%)	
None of these syringes				**0.004**
No	140 (56.7%)	149 (70.3%)	289 (63.0%)	
Yes	107 (43.3%)	63 (29.7%)	170 (37.0%)	

Lifestyle				
Transport to hospital				0.088
Walking				
Never / sometimes	213 (91.0%)	181 (85.4%)	394 (88.3%)	
Often / always	21 (8.97%)	31 (14.6%)	52 (11.7%)	
Bicycle or scooter				0.334
Never / sometimes	207 (88.5%)	180 (84.9%)	387 (86.8%)	
Often / always	27 (11.5%)	32 (15.1%)	59 (13.2%)	
Public transport				0.667
Never / sometimes	215 (91.9%)	198 (93.4%)	413 (92.6%)	
Often / always	19 (8.12%)	14 (6.60%)	33 (7.40%)	
Private car (alone)				0.193
Never / sometimes	63 (26.9%)	70 (33.0%)	133 (29.8%)	
Often / always	171 (73.1%)	142 (67.0%)	313 (70.2%)	
Carpool				0.530
Never / sometimes	225 (96.2%)	207 (97.6%)	432 (96.9%)	
Often / always	9 (3.85%)	5 (2.36%)	14 (3.14%)	
Recycling at home and hospital				**0.002**
No	18 (7.29%)	2 (0.94%)	20 (4.36%)	
Yes	229 (92.7%)	210 (99.1%)	439 (95.6%)	
Facilities and Barriers				
Sustainability info from companies				0.276
No	184 (74.5%)	168 (79.2%)	352 (76.7%)	
Yes	63 (25.5%)	44 (20.8%)	107 (23.3%)	
Barrier				
Lack of awareness/training				0.853
No	60 (24.3%)	49 (23.1%)	109 (23.7%)	
Yes	187 (75.7%)	163 (76.9%)	350 (76.3%)	
High cost				0.655
No	193 (78.1%)	161 (75.9%)	354 (77.1%)	
Yes	54 (21.9%)	51 (24.1%)	105 (22.9%)	
Resistance to change				**0.021**
No	95 (38.5%)	59 (27.8%)	154 (33.6%)	
Yes	152 (61.5%)	153 (72.2%)	305 (66.4%)	
Lack of guidelines				**0.002**
No	129 (52.2%)	79 (37.3%)	208 (45.3%)	
Yes	118 (47.8%)	133 (62.7%)	251 (54.7%)	
Lack of eco-friendly technology				0.134
No	151 (61.1%)	114 (53.8%)	265 (57.7%)	
Yes	96 (38.9%)	98 (46.2%)	194 (42.3%)	