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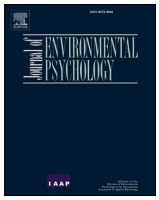

What does sustainability sound like? Crafting soundscapes that reflect environmental and social sustainability dimensions

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ABSTRACT

This paper presents a series of studies examining how music and soundscapes can convey the abstract and multidimensional concept of sustainability. A pilot study identified concrete sensory and affective descriptors linked to sustainability (e.g., *natural*, *responsible*), which were then used to determine psychoacoustic properties (e.g., pitch, consonance) capable of communicating these descriptors. Based on these properties, ten instrumental musical soundtracks were selected and evaluated for their capacity to evoke sustainability associations. The soundtracks were adapted to reflect environmental (overlaying jungle, forest, or beach sounds; Study 1) and social (overlaying talking, laughing, or cheering sounds; Study 2) dimensions. Results (combined $N = 517$) indicated that soundtracks aligned with sustainability descriptors reliably elicited strong perceptions of sustainability. Additionally, overlaying nature sounds enhanced associations with environmental sustainability, while incorporating human group sounds increased social sustainability associations. These findings demonstrate the potential of music and soundscapes to communicate abstract concepts, highlighting the importance of integrating musical elements with explicit sounds to evoke targeted sustainability perceptions. Harnessing such soundscapes may offer new avenues for organizations to communicate sustainability, with potential applications in brand and product experiential design.

1. Introduction

To address the challenges of a growing population, the United Nations has emphasized the need for transformative changes in production and consumption models (United Nations, 2015). While this transformation requires action from governmental bodies and organizations, successful implementation critically depends on how sustainability is interpreted by individuals in everyday contexts (Arias Puentes & Trujillo, 2025; Testa et al., 2018). A key challenge in this process involves helping people make sense of and embody sustainability-related information. These transformations span both environmental aspects, such as conserving biodiversity and reducing pollution, and social ones, such as promoting equity and collective well-being (Sheth et al., 2011).

One way to support this individual-level understanding of sustainability is to provide cues about the sustainability features of a product. Informative cues can educate consumers about product attributes, helping them make decisions that better align with their values and preferences (Annunziata et al., 2011; Lv et al., 2024). Other cues (e.g., packaging textures and colors) can evoke a general sense of sustainability without detailed explanation (Granato et al., 2022; Sokolova et al., 2023). Such subtle cues may offer a less cognitively demanding way to influence perceptions, shaping how people interpret the sustainability of products, services, and experiences.

Among the various types of sustainability cues, visual elements are the most prevalent. These may include logos, design features, and packaging claims that often emphasize a product's environmental

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attributes (Granato et al., 2022; Hallez et al., 2023; Magnier & Schoormans, 2015). These visual cues provide useful information, especially when time or attention is limited, but they can also be difficult to interpret. For example, as of 2024, the Ecolabel Index identified 456 ecolabels across 199 countries, each addressing different aspects of sustainability (Ecolabel Index, 2024). Additionally, diverse sustainability-related claims in product packaging, such as "locally produced" or "made from recycled materials", may further complicate consumer decision-making (Janβen & Langen, 2017). While such explicit cues play an important role in communicating sustainability, exploring complementary channels may offer additional ways to enhance consumers' perception and understanding.

An alternative and potentially effective approach to communicating sustainability involves sensory nudges (i.e., subtle cues that unconsciously influence consumer choices; Selinger & Whyte, 2011) across various modalities. The sustainability-related multisensory context, accompanied by an informative discourse on sustainability, has been demonstrated to influence decision-making toward sustainable foods (Zandstra et al., 2025). Auditory cues, in particular, represent a relatively untapped modality in sustainable communication (e.g., music to signal product eco-friendliness; Spence & Keller, 2024). Although background sounds are increasingly used in advertising, their application to sustainability messaging remains uncommon.

Sonic logos are one example whereby short melodies engage attention and emotions while communicating the essence of a brand's identity (Ayada & Ragab, 2024; Scott et al., 2022). When designing these logos, designers seek to ensure congruence with the ideas, feelings, and concepts associated with the products they intend to represent. For example, Techawachirakul et al. (2023) demonstrated that sonic logos with "feminine" timbres (e.g., flute, violin) are perceived as more suitable for plant-based products. Additional studies on the role of sound in shaping consumers' experience and perception have explored how brand name sounds can influence perceptions of eco-friendliness in products like pens and sunscreen (Joshi & Kronrod, 2020) or how songs with prosocial lyrics encourage purchases of fair-trade (*vs.* regular) coffee (Ruth, 2017). Soundscapes, such as nature sounds or specific music genres, can also match with organic and eco-friendly food products, increasing their purchase intentions (Esteky, 2021; Motoki et al., 2024; Spendrup et al., 2016; Zandstra et al., 2025). Together, these studies suggest that sound carries the potential to communicate product meanings, including sustainability attributes.

Despite growing interest in the role of sound in communicating environmentally friendly attributes, systematic research on how auditory stimuli are associated with sustainability meanings—especially encompassing social and environmental dimensions—remains relatively scarce compared to other fields such as health communication (Motoki & Togawa, 2022). To help bridge this gap, the present work examines how music and soundscapes may relate to the abstract and multidimensional concept of sustainability. Drawing on insights from crossmodal research, we propose a novel set of auditory stimuli designed to evoke sustainability-related associations (Spence & Keller, 2024). Prior work in this area suggests that auditory stimuli can evoke associations with attributes in different sensory modalities (e.g., sounds triggering flavor or olfactory associations; Rodríguez et al., 2024) as well as affective states (e.g., sounds eliciting specific emotions; Guedes et al., 2023). Building on these findings, we hypothesize that soundscapes can communicate sustainability through sensory and affective concrete features that people associate with this concept. The following section further elaborates on the conceptual framework behind these associations and outlines our approach to developing the stimulus set.

2. Conceptual development

2.1. Dimensions of sustainability and consumer impacts

A major challenge in sustainability messaging is defining what sustainability encompasses. Research indicates that individual conceptions of sustainability should mirror its multidimensional nature (Barone et al., 2020), with the environmental aspect often standing out through concerns about ecosystem impact and resource efficiency (Giovannoni & Fabietti, 2013; Hanss & Böhm, 2012; Kronrod et al., 2023). However, the global sustainability discourse increasingly underscores the interconnections between environmental and social factors (Purvis et al., 2019; Wilkins, 2008). For instance, climate change disproportionately affects marginalized communities and vulnerable social groups (Berberian et al., 2022; Frosch et al., 2018; Thomas et al., 2019). In addition to such uneven impacts, the degradation of ecosystems threatens multiple dimensions of human well-being, including social cohesion, material resources, security, and health (Millennium Ecosystem Assessment, 2005). These multiple dimensions make the sustainability concept especially challenging to communicate in a way that captures its full scope.

In light of the growing public awareness of global sustainability challenges, consumers are increasingly prioritizing eco-friendly options (Cam, 2023; Fraj & Martinez, 2007), yet sustainable consumer choices must also consider issues such as economic fairness and proper working conditions for producers (Andorfer & Liebe, 2012). The Fair Trade movement (Walton, 2010) exemplifies initiatives to promote fair practices in international trade by encouraging consumers to support socially responsible products. Thus, further exploration of the diverse factors shaping sustainable consumer perceptions is necessary. While much of the research focuses on individual factors such as personal values and attitudes (Coppola et al., 2017), contextual influences, particularly the multisensory factors, also play a fundamental role in shaping consumer behavior (Sarstedt, Imschloss, & Adler, 2024; Spence et al., 2014; Velasco & Spence, 2019). Understanding how these contextual factors operate is essential for designing more effective strategies to promote sustainable consumption. Further research is needed to explore these dynamics in greater depth and to translate them into actionable insights (Syed et al., 2024).

2.2. Using sound to communicate sensory and affective attributes

Consumer experiences are inherently multisensory, shaped by a range of contextual cues. This multisensory nature often draws on a combination of product-related touchpoints (e.g., packaging, labeling, and branding) and extrinsic sensory cues (e.g., ambient music and soundscapes; Velasco & Spence, 2019). These elements work together to influence how consumers perceive and engage with products, contributing to an immersive experience that extends beyond functional product characteristics (as in the experience economy; Pine & Gilmore, 1998). Among extrinsic cues, music plays a unique role by conveying both embodied meaning (arising directly from the music's acoustic features) and referential meaning (shaped by external, contextual, and semantic associations; Meyer, 1956). Musical stimuli, thus, contribute to how consumers construct meaning around product experiences.

One key mechanism by which music influences perception is through crossmodal correspondences, defined as systematic associations between sensory information from different modalities (Spence, 2011). These associations, classified as physiological, statistical, semantic, and affective, help explain how soundscapes can evoke specific sensory or emotional impressions (Motoki et al., 2023). For instance, lower-level sound attributes, such as loudness, engage sensory receptors directly (e.g., hair cells in the cochlea; Purves et al., 2001), while higher-level attributes like musical harmony or rhythm integrate these lower-level features into more complex experiential meanings (Spence, 2020). By reinforcing embodied and referential meanings, crossmodal correspondences provide a framework for designing tailored perceptual experiences by linking specific sound elements to intended sensory or affective associations.

2.2.1. Affective congruency

Affective congruency links sensory stimuli through associated affective meanings even without perceptual similarity between matched stimuli (Di Stefano & Spence, 2024). This influence is particularly strong in correspondences involving high-level cognitive stimuli (e.g., music) compared to low-level perceptual inputs (e.g., pure tones; Spence, 2020). Numerous studies have documented this mediation in music-color and music-flavor correspondences (Barbiere et al., 2007; Isbilen & Krumhansl, 2016; Reinoso-Carvalho et al., 2016, 2019). When affectively congruent stimuli are processed across modalities, they tend to be processed more fluently, enhancing aesthetic appreciation (Spence, 2020). This affective dimension supports the use of emotionally aligned auditory cues in multisensory strategies, which may serve as an aesthetically pleasing bridge to further perceptions.

A primary reason people engage with music is its ability to evoke emotions, memories, and mood states, making it a powerful component in consumer experiences (Juslin & Västfjäll, 2008). In marketing contexts, for instance, customized soundscapes can enhance emotional engagement without altering the product's intrinsic features. As such, music serves as a communication resource that aligns with consumers' internalized affective values and perceptions.

2.2.2. Sensory congruency

Physiological, statistical, and semantic accounts of crossmodal correspondences demonstrate that sensory stimuli can align with other sensory attributes without affective influence. Physiological and statistical correspondences involve neural codes underlying sensory stimuli or internalized environmental regularities, typically for low-level perceptual stimuli (Motoki et al., 2023). For example, the correspondence between pitch and spatial elevation of sound is attributed to statistical learning of environmental sensory regularities (Parise et al., 2014). Semantically mediated (linguistic) correspondences arise from applying semantic descriptors, either explicitly or implicitly, to sensory perceptions across modalities, often through language (Motoki et al., 2023). For instance, birdsongs semantically link to nature (Esteky, 2021), reinforcing the potential for soundscapes to evoke associations with such semantic attributes. In brief, soundscapes can be designed to correspond to concrete sensory perceptions, thereby guiding auditory communication.

2.3. Concrete descriptors of the sustainability concept and its dimensions

The abstract nature of sustainability presents a challenge in terms of communication. Grounded cognition theory (Barsalou, 2007) offers a useful framework to address this challenge by proposing that all cognition, including abstract concepts, is grounded in experience through two different pathways: directly through sensorimotor and emotional interaction with the world, and indirectly through linguistic and social processes (Reinboth & Farkaš, 2022). From this perspective, abstractness is not a binary trait but a continuum, meaning that even highly abstract constructs can be partially grounded by connecting them to concrete perceptual experiences. Thus, we propose that sensory and affective cues offer a promising route to disentangle the meaning of sustainability and make it more accessible.

Complementing this view, the theory of spreading activation in semantic memory (Collins & Loftus, 1975) explains that external stimuli can trigger related concepts by activating interconnected nodes in our mental networks. Concrete sustainability descriptors can be activated through related soundscapes, achieving sensory and affective congruency that indirectly activates abstract sustainability dimensions by grounding them in familiar perceptual experiences. These activations are supported by research, including findings that low-saturation colors are implicitly associated with eco-friendliness (Pichierri & Pino, 2023) and that textural complexity in food can nudge consumers toward sustainable choices in the absence of explicit messages (Baylan & Ozilgen, 2024). Similarly, sensory exposure to nature can elicit self-transcendent emotions like happiness and gratitude, which in turn promote pro-environmental behaviors (Zelenski & Desrochers, 2021).

Drawing on the body of crossmodal literature (e.g., Barone et al., 2020; Stancu et al., 2020; van Bussel, Kuijsten, Mars, & van t Veer, 2022), we compiled a list of sensory (i.e., *blue*, *circular*, *close*, *cold*, *earthy*, *floral*, *fresh*, *fruity*, *green*, *light*, *lush*, *quiet*, *raw*, *slow*, *small*, *soft*, *white*, and *woody*) and affective descriptors (i.e., *active*, *balanced*, *calm*, *connected*, *continuous*, *cute*, *empathetic*, *ethical*, *familiar*, *grateful*, *happy*, *harmonious*, *hopeful*, *inspiring*, *lovely*, *natural*, *pure*, *responsible*, *safe*, *serene*, *simple*, *trustworthy*, and *wholesome*) empirically linked to sustainability-related perceptions, intentions, and behaviors. Accordingly, when sensory inputs align with pre-existing mental representations (e.g., muted tones with naturalness, or textured visuals with low-waste connotations), they reinforce sustainability perceptions. When sound features align with these descriptors, they may help ground the abstract notion of sustainability in embodied experience.

Sound, in particular, has the potential to evoke many of these grounded sensory and affective qualities. For example, Anikin and Johansson (2018) demonstrate that loudness and pitch correlate with color saturation. If muted visual tones imply environmental friendliness, then lower-pitched, softer, or less saturated sounds may spread to trigger similar impressions. Such congruent mappings allow soundtracks—defined here as instrumental music without lyrics or explicit informative content—to embody the perceptual qualities that, for example, visual stimuli use to signal sustainability. In this way, soundtracks can be strategically designed to support sustainability messaging.

On the other hand, non-musical sounds such as natural ambiences or voices can activate different dimensions of sustainability. For example, pro-environmental behaviors have been triggered by natural soundscapes (e.g., birdsong; Esteky, 2021; Zandstra et al., 2025). Additionally, prosocial behaviors could be activated through increased perceptions of social presence (J. Wang & Dai, 2020), and the presence of voices have been empirically associated with perceptions of safety, lightness, and freshness (Dennis, 2021; Devos et al., 2019; Mahdavi et al., 2020; Sayin et al., 2015), qualities that align with key attributes of social sustainability. Therefore, affective and sensory meanings embedded in non-musical sounds can also implicitly convey distinct sustainability dimensions (e.g., environmental or social sustainability).

3. Overview of studies

This paper presents three interconnected studies investigating how soundscapes can convey the concept of sustainability (see Fig. 1). First, a Pilot Study was conducted to identify which sensory and affective descriptors best corresponded to the concept of sustainability. The goal of this study was to translate this abstract, multidimensional concept into concrete descriptors that could then be linked to specific psychoacoustic attributes. Next, drawing on a literature review, we selected a set of psychoacoustic features related to these descriptors, which then guided the development of the soundtrack set. In the next phase, we evaluated the effectiveness of these soundtracks in eliciting associations with sustainability across two empirical studies. These studies sought to tap into different facets of sustainability by combining these soundtracks with natural (Study 1) and human sounds (Study 2). This structured approach, transitioning from conceptual groundwork to empirical testing, provides a framework for examining the ability of soundscapes (i.e., soundtracks combined with non-musical sounds) to communicate abstract concepts.

Our hypotheses drew on the conceptual understanding of music's ability to convey abstract concepts, supported by the grounded cognition theory. We further integrated crossmodal correspondences between sustainability descriptors (environmental and social) and specific non-music sound elements described in Section 5. The proposed hypotheses were as follows (see Fig. 1 for their connection with the studies).

H1. Soundtracks designed to be congruent with sensory and affective

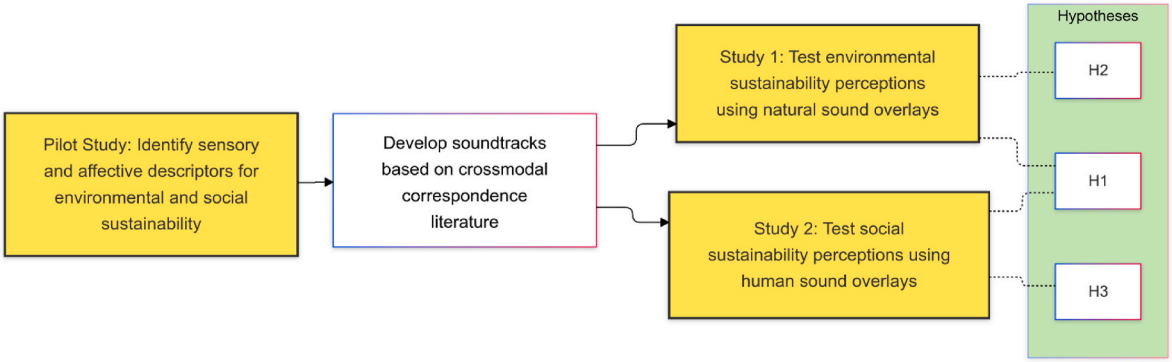

Fig. 1. Research framework depicting the relationships among the studies and hypotheses proposed in the present paper.

sustainability descriptors evoke stronger sustainability associations than non-congruent soundtracks.

H2. Layering nature-related sounds over sustainability-congruent soundtracks enhances perceptions of environmental sustainability compared to instrumental tracks alone.

H3. Adding human group sounds to sustainability-congruent soundtracks evokes stronger associations with social sustainability compared to instrumental music alone.

These hypotheses reflect the multidimensional nature of sustainability and highlight how distinct sound elements can selectively enhance specific sustainability dimensions.

In designing our research, we chose not to test natural sounds and voices in isolation but as layered elements within sustainability-congruent soundtracks. This decision stemmed from our focus on creating cohesive soundscapes with real-world application potential, particularly in sonic branding and marketing contexts. Combining stand-alone sound elements within structured musical compositions better aligns with their practical applications in commercial contexts. By embedding nature-related and human group sounds into the soundtracks, we aimed to create an ecologically valid design that reflects realistic auditory experiences such as those in communication plans.

4. Pilot study: Finding sustainability descriptors

This study aimed to empirically identify sensory and affective concepts associated with the environmental and social dimensions of sustainability. The ultimate goal was to translate the abstract concept of sustainability into a set of concrete descriptors that could later be mapped onto specific psychoacoustic attributes for use in soundscape design. Using a between-subjects design, participants were asked to evaluate the extent to which various sensory and affective attributes aligned with either environmental or social sustainability. This approach enabled a comparative analysis of how each sustainability dimension is represented in terms of sensations and emotions, laying the groundwork for the development of sound-based stimuli capable of conveying these distinct aspects.

4.1. Materials and methods

One hundred and ninety-eight participants (M_{age} = 30, SD_{age} = 10 years; 51 % male, 48 % female, 1 % non-binary) were recruited *via* Prolific (https://www.prolific.com/). Each participant was remunerated 0.60 pounds sterling.

This study assessed two categories of descriptors: sensory and affective. Based on prior literature (see Section 2.3), 18 sensory and 23 affective descriptors were selected. The sensory descriptors included *blue*, *circular*, *close*, *cold*, *earthy*, *floral*, *fresh*, *fruity*, *green*, *light*, *lush*, *quiet*, *raw*, *slow*, *small*, *soft*, *white*, and *woody*. The affective descriptors included *active*, *balanced*, *calm*, *connected*, *continuous*, *cute*, *empathetic*, *ethical*, *familiar*, *grateful*, *happy*, *harmonious*, *hopeful*, *inspiring*, *lovely*, *natural*, *pure*, *responsible*, *safe*, *serene*, *simple*, *trustworthy*, and *wholesome*.

The survey was conducted online *via* Qualtrics (Qualtrics, 2020), delivered in English, and lasted approximately 4 min. After providing informed consent, participants read a sentence emphasizing that sustainability encompasses multiple dimensions. Half of the participants were assigned to the environmental dimension of sustainability, and the other half to the social dimension. Participants rated the degree to which they associated each sensory and affective descriptor with the corresponding sustainability dimension on a seven-point scale (1 = *Not at all associated*, 7 = *Totally associated*).

4.2. Results

To assess the extent of the associations with each dimension of sustainability included, the average ratings for all descriptors were compared. For both environmental and social dimensions, descriptors were ranked from lowest to highest based on their mean ratings. These rankings were then divided into quartiles, allowing us to identify the top-quartile descriptors, namely the sensory and affective experiences most consistently associated with each sustainability dimension.

The results revealed consistent associations between sensory and affective descriptors and the environmental and social dimensions of sustainability (see Tables 1 and 2). Among the sensory descriptors, *green*, *fresh*, and *earthy* consistently ranked in the highest quartile for both

Table 1
Average ratings for sensory descriptor associations with environmental and social sustainability.

Descriptor	Environmental rating M (SD)	Social rating M (SD)
Blue	3.9 (1.9)	3.1 (2.0)
Circular	4.1 (1.9)	3.6 (1.8)
Close	3.1 (1.7)	3.6 (1.9)
Cold	3.3 (1.9)	2.7 (1.6)
Earthy	5.8 (1.5)*	4.3 (1.9)*
Floral	4.6 (1.7)*	3.3 (2.0)
Fresh	5.0 (1.6)*	4.2 (1.9)*
Fruity	3.9 (1.9)	3.2 (1.9)
Green	6.0 (1.3)*	4.6 (2.0)*
Light	4.2 (1.7)	3.9 (1.8)*
Lush	3.5 (1.8)	3 (1.9)
Quiet	3.8 (1.9)	3.6 (1.8)*
Raw	4.1 (1.7)	3.3 (1.9)
Slow	3.4 (1.8)	3 (1.7)
Small	2.8 (1.6)	3 (1.7)
Soft	3.2 (1.6)	3.5 (1.9)
White	3.2 (1.8)	3.2 (2.0)
Woody	4.6 (1.7)*	3.1 (1.9)

Note. M = mean; SD = standard deviation. Quartiles were calculated separately for each sustainability dimension, and ratings within the top quartile for each dimension are signaled with an asterisk.

Table 2
Average ratings for affective descriptor associations with environmental and social sustainability.

Descriptor	Environmental rating *M* (*SD*)	Social rating *M* (*SD*)
Active	**4.6 (1.8)**	**4.8 (1.7)**
Balanced	5.4 (1.5)*	5.3 (1.5)*
Calm	4.4 (1.9)	4.3 (1.9)
Connected	4.8 (1.8)	5.2 (1.6)*
Continuous	4.9 (1.7)	4.4 (1.8)
Cute	3.0 (1.9)	3.2 (1.9)
Empathetic	4.4 (1.9)	5.1 (1.8)
Ethical	5.6 (1.6)*	5.6 (1.5)*
Familiar	4.0 (1.8)	4.4 (1.8)
Grateful	4.2 (1.8)	4.5 (1.9)
Happy	4.6 (1.8)	4.8 (1.8)
Harmonious	5.1 (1.7)	5.0 (1.6)
Hopeful	5.0 (1.9)	5.1 (1.6)
Inspiring	4.7 (1.9)	5.0 (1.8)
Lovely	3.9 (2.0)	4.0 (2.0)
Natural	6.1 (1.1)*	5.1 (1.8)
Pure	5.1 (1.7)*	4.4 (1.9)
Responsible	5.7 (1.5)*	5.5 (1.4)*
Safe	5.2 (1.7)*	5.2 (1.5)*
Serene	4.2 (1.8)	4.3 (1.8)
Simple	4.3 (1.8)	4.0 (1.8)
Trustworthy	4.6 (1.9)	4.8 (1.7)
Wholesome	4.4 (1.9)	4.6 (1.9)

Note. M = mean; SD = standard deviation. Quartiles were calculated separately for each sustainability dimension, and ratings within the top quartile for each dimension are signaled with an asterisk.

environmental and social sustainability, indicating strong associations with both dimensions. The descriptors *floral* and *woody* were highly linked to environmental sustainability, while *light* and *quiet* were clearly associated with the social dimension. Similarly, within the affective descriptors, *safe*, *responsible, balanced*, and *ethical* ranked in the highest quartile for both environmental and social sustainability. The descriptors *natural* and *pure* were strongly associated with environmental sustainability, whereas *connected* was linked to the social dimension.

The findings of this study illustrated the interplay between environmental and social sustainability through sensory and affective experiences. *Balanced*, *earthy*, *ethical*, *fresh*, *green*, *responsible*, and *safe* served as conceptual bridges between both dimensions. In contrast, *floral*, *natural*, *pure*, and *woody* leaned more toward environmental sustainability, whereas *connected*, *light*, and *quiet* appeared specific to the social dimension. These results highlighted both overlap and distinct associations between these dimensions.

Previous studies on sustainability associations emphasize its conceptual ambiguity and rely on broad descriptions (e.g., *recycling*, *organic*; Barone et al., 2020; Stancu et al., 2020). While these studies provided thematic clusters of consumer associations, they did not clarify how different sustainability dimensions (i.e., environmental vs. social) might evoke distinct sensory or affective associations. Moreover, to our knowledge, no empirical research had translated the sustainability concept into concrete sensory or affective representations that could inform communication strategies. Addressing this gap, the present pilot study mapped sensory and affective descriptors to the environmental and social dimensions of sustainability, operationalizing them as experiential constructs. This mapping bridged cognitive and perceptual domains, a connection that is particularly relevant for sound design.

5. Development of soundtracks: translating sustainability descriptors into sound

The pilot study revealed key sensory and affective descriptors highly aligned with environmental and social sustainability. Grounded in the spreading activation theory within semantic memory networks, these descriptors informed the identification of sound elements potentially evoking sustainability perceptions. Crossmodal correspondences further suggest that these sound elements can trigger specific sensory and affective responses. Consequently, soundtracks developed based on sustainability-related descriptors could contribute to soundscapes that evoke and reinforce sustainability perceptions.

Crossmodal research has established empirical connections between the sustainability descriptors identified in the pilot study (i.e., *balanced*, *connected*, *earthy*, *ethical*, *floral*, *fresh*, *green*, *light*, *natural*, *pure*, *quiet*, *responsible*, *safe*, and *woody*) and corresponding sound elements (e.g., Rodríguez et al., 2024). These associations were explored through a variety of sounds, including natural recordings, short musical pieces, custom notes, melodies, and songs. Analyzing these sounds, broken down into fundamental elements such as tempo, pitch, and roughness, provided a more abstract understanding of crossmodal correspondences (Rodríguez et al., 2023). Table 3 summarizes the fundamental elements linked to sustainability descriptors, including psychoacoustic properties (i.e., pitch, tempo, mode, timbre, articulation, and consonance), natural sounds, voice, instrumentation, and affective qualities. Based on these findings, we identified ten soundtracks featuring sound elements aligned with sustainability (e.g., high pitch) to form the putative "sustainable" list, and five soundtracks with opposing attributes (e.g., low pitch) to form the putative "contrasting" list. For a detailed description of the soundtrack selection process, including input from music experts, refer to Supplementary File 1, available at osf.io/nyzbp.

6. Study 1: the sound of environmental sustainability

Study 1 aimed to validate the soundtracks selected in Section 5 by collecting subjective ratings from a new pool of participants. Participants evaluated the associations between the curated music and the sensory and affective sustainability descriptors identified in the pilot study. On top of that, Study 1 explored the effect of overlaying nature-related soundscapes (i.e., beach, forest, and jungle) on sustainability descriptors, particularly those related to environmental sustainability (see Table 3).

6.1. Materials and methods

6.1.1. Participants and design

Two-hundred and sixty participants aged 18–91 (M_{age} = 34; SD_{age} = 12 years; 49.6 % male, 47.3 % female, 2.3 % non-binary, 0.4 % trans men, 0.4 % preferred not to answer) were recruited *via* Prolific. Each participant was remunerated 2.25 pounds sterling. An a priori power analysis was conducted using G*Power v3.1.9 (Faul et al., 2007) with an effect size of 0.20. Given a significance level of $\alpha = .05$ and a power of 0.99, the minimum required sample size for ANOVA was 70. Nonetheless, a larger sample was selected to account for the number of soundtracks developed.

6.1.2. Materials

The study tested 45 soundtracks: four versions of each of the ten putative sustainable soundtracks (original and three overlaid versions) and five putative contrasting soundtracks (see Section 5). A psychoacoustic characterization of the ten original putative sustainable soundtracks and the five putative contrasting ones is available in Supplementary File 3 at osf.io/zmf54. The overlaid versions of the sustainable soundtracks were produced by layering three thematic natural soundscapes. Previous research has shown that blending music and natural sounds may contribute to a unique affective experience, which differs from delivering either stimulus alone (Smalley et al., 2023). As such, three natural scenes were chosen to reflect different environments and moods, namely, beach (characterized by sounds of water, waves, and wind), forest (wind, leaves rustling, birds chirping), and jungle (soft rain sounds, birds chirping). These natural soundscapes were chosen to reflect diverse sonorities and evoke associations with distinct ecosystems and geographical contexts. All soundtracks were professionally

Table 3
Crossmodal correspondences between sustainability descriptors and sound elements.

Descriptor	Sound element	References
Connected (n = 3 studies)	Sound of water	Ray et al. (2021)
	Instrumental	de Leeuw et al. (2022)
	Nature sounds	(Ray et al., 2021; Spendrup et al., 2016)
Floral (n = 4 studies)	Low tempo	Rodríguez et al. (2024)
	Major mode	Rodríguez et al. (2024)
	High pitch	(Crisinel et al., 2013; Lee, 2013)
	Woodwind	Rodríguez et al. (2024)
	Legato	Rodríguez et al. (2024)
	Piano	(Crisinel et al., 2013; Crisinel & Spence, 2012a; Rodríguez et al., 2024)
	Soft music	Mahdavi et al. (2020)
	Wind sound	Mahdavi et al. (2020)
Fresh (n = 3 studies)	Sound of water	Mahdavi et al. (2020)
	Soft voices	Mahdavi et al. (2020)
	High-pitched voices	Mahdavi et al. (2020)
	Mid-high pitch	Lee (2013)
	Low tempo	Rodríguez et al. (2024)
	Woodwind	Rodríguez et al. (2024)
	Legato	Rodríguez et al. (2024)
	Voices	Mahdavi et al. (2020)
	Nature sounds	Mahdavi et al. (2020)
Green (n = 10 studies)	Low roughness	Sun et al. (2018)
	Low tempo	(Palmer et al., 2013; Rodríguez et al., 2024)
	Major mode	(Palmer et al., 2013; Tsang & Schloss, 2010)
	High pitch	(Simpson et al., 1956; Spence & Di Stefano, 2022)
	Woodwind	(Bologna et al., 2007; Quero et al., 2021; Rodríguez et al., 2024; Spence & Di Stefano, 2022)
	Soft timbre	(Adeli et al., 2014; Spence & Di Stefano, 2022)
	Happy music	Barbiere et al. (2007)
	Legato	Rodríguez et al. (2024)
Light (n = 4 studies)	Soft voices	Mahdavi et al. (2020)
	Low tempo	Rodríguez et al. (2024)
	Major mode	(Quero et al., 2021; Rodríguez et al., 2024)
	Legato	Rodríguez et al. (2024)
	Voices	Mahdavi et al. (2020)
	Nature sounds	Mahdavi et al. (2020)
	Calm music	Mahdavi et al. (2020)
	Woodwind	Rodríguez et al. (2024)
	Piano	Rodríguez et al. (2024)
	High pitch	Crisinel and Spence (2012b)
Morality (n = 1 study)	High pitch	Huang & Labroo (2020)
Natural (n = 1 study)	Low tempo	Rodríguez et al. (2024)
	Woodwind	Rodríguez et al. (2024)
	Legato	Rodríguez et al. (2024)
	Nature sounds	Rodríguez et al. (2024)
Pure (n = 1 study)	Pleasant	Lahdelma and Eerola (2020)
	Consonance	Lahdelma and Eerola (2020)
	Smoothness	Lahdelma and Eerola (2020)
Safety (n = 5 studies)	Soft voices	Devos et al. (2019)
	Low tempo	Dennis (2021)
	Instrumental	Schäfer et al. (2015)
	Foreground sounds (e.g., bells, typewriter)	(Andringa & Lanser, 2013; Devos et al., 2019)
	Voices	(Dennis, 2021; Devos et al., 2019; Sayin et al., 2015)
	Pleasant	Andringa and Lanser (2013)
	Quiet	Andringa and Lanser (2013)
Woody (n = 3 studies)	Low tempo	Rodríguez et al. (2024)
	Major mode	Rodríguez et al. (2024)
	Woodwind	Rodríguez et al. (2024)
	Legato	Rodríguez et al. (2024)
	Piano	Rodríguez et al. (2024)
	Rain sound	Rodríguez et al. (2024)
	Low-pitched voices	Mahdavi et al. (2020)
	Mid-low pitch	Lee (2013)
	Smoothness	Mahdavi et al. (2020)

edited to ensure comparable sound pressure levels and loudness, lasting 60 s with gradual fade-in and fade-out. All files are publicly available at osf.io/x3gsp/.

6.1.3. Measures

In the first block, participants rated how strongly they associated each soundtrack with the 14 sensory and affective sustainability descriptors identified in the pilot study using a seven-point scale (1 = *Not at all associated,* 7 = *Totally associated*). In the second block, participants evaluated the soundtracks on four seven-point scales in valence (1 = *Very negative*, 7 = *Very positive*), arousal (1 = *Not at all arousing*, 7 = *Very arousing*), liking (1 = *I don't like it at all*, 7 = *I like it very much*), and familiarity (1 = *Not at all familiar*, 7 = *Very familiar*). They also rated global sustainability, as well as social and environmental sustainability associations, on seven-point scales (1 = *Not at all associated*, 7 = *Totally associated)*.

6.1.4. Procedures

The survey was programmed in Qualtrics and administered online. After providing informed consent, participants completed a brief questionnaire with basic sociodemographic questions, such as age, gender, country of birth, and country of residence.

Before the main task, participants were instructed to set their audio device to a comfortable volume level using a sample sound. To ensure proper headphone use, two control items were included: (1) identifying a snippet of birds chirping and (2) determining the direction from which they perceived the sound—left or right. Participants who provided incorrect responses were redirected to the end of the survey without receiving compensation.

As the main task, participants listened to a subset of nine soundtracks—eight "sustainable" (two for each version: original, beach, jungle, forest) and one "contrasting"—and evaluated them. To ensure an even distribution of the "sustainable" versions and avoid repetition of soundtracks (e.g., presenting the same soundtrack in two different versions), 10 predefined stimulus lists were produced. Participants were then randomly assigned to one of these lists, where the order of stimulus presentation within each list was also randomized. The number of participants who listened to each soundtrack is available in Supplementary File 2 at osf.io/uhcdn.

The soundtracks played automatically and continuously throughout the evaluation task, with sound controls (e.g., pause) concealed from participants. Participants could only proceed with the survey after listening to the complete soundtrack at least once (i.e., after 60 s). The evaluation consisted of three main blocks of questions described in the Measures subsection. Within each block, the items were presented in random sequence.

The soundtrack evaluation task was followed by a set of control items designed to ensure the quality of responses. Participants were asked to report any events that may have interfered with their responses (e.g., technical issues, interruptions) and to reconfirm their use of headphones. At the end of the survey, participants were provided with a debriefing and received their monetary compensation. All procedures were performed in compliance with the Declaration of Helsinki and institutional guidelines and were approved by the Ethics Committee of an academic department (case 481 of 2023).

6.1.5. Data analytic plan

A repeated-measures ANOVA was conducted to compare the "sustainable" (S1–S10) and "contrasting" soundtracks (C1–C5). The soundtrack category (original sustainable *vs.* contrasting) was the independent variable, while global, environmental, and social sustainability ratings were the dependent variables. For each participant, average scores for the randomly assigned original soundtracks were calculated. Soundtrack category (i.e., original, beach, forest, jungle, and contrasting) averages for each sustainability descriptor were also analyzed.

Norming data for all 45 soundtracks included means, standard deviations, and confidence intervals for each evaluative dimension. Ratings were categorized as low (upper bound below midpoint), moderate (confidence interval includes midpoint), or high (lower bound above midpoint), following the procedure described by Guedes et al. (2023).

To assess the incremental value of overlaying soundscapes, a repeated-measures ANOVA compared the original, beach, jungle, and forest versions of S1–S10 across global, social, and environmental sustainability items. For each version, average scores were calculated from the soundtracks assigned to each participant (e.g., mean beach ratings). Significance was evaluated at a 95 % confidence level.

6.2. Results

The mean scores on the sustainability descriptors revealed notable differences between the "sustainable" and the "contrasting" soundtracks (Fig. 2). A main effect of the soundtrack category (original sustainable *vs.* contrasting) was observed across global, environmental, and social sustainability ratings, $F(3, 236) = 52.88$, $p < .001$, $\eta_p^2 = 0.40$. Pairwise comparisons showed that original sustainable soundtracks received significantly higher ratings than the contrasting ones across all three measures (all $p < .001$).

6.2.1. Norming data

Complete normative data are available as supplemental material (see Supplementary File 2 at osf.io/uhcdn). Fig. 3 illustrates the distribution of all "sustainable" soundtracks (S1-S10 in all four versions) across low, moderate, and high levels in all evaluative dimensions. Most soundtracks were rated moderate or high for global (31/40) and environmental sustainability (32/40). In contrast, ratings for social sustainability were low and moderate, with no soundtrack rated high in this dimension. Across sensory and affective descriptors, the soundtracks were generally rated moderate or high, except for *quiet*, *floral*, and *woody*, which had more soundtracks rated low compared to the rest of the descriptors.

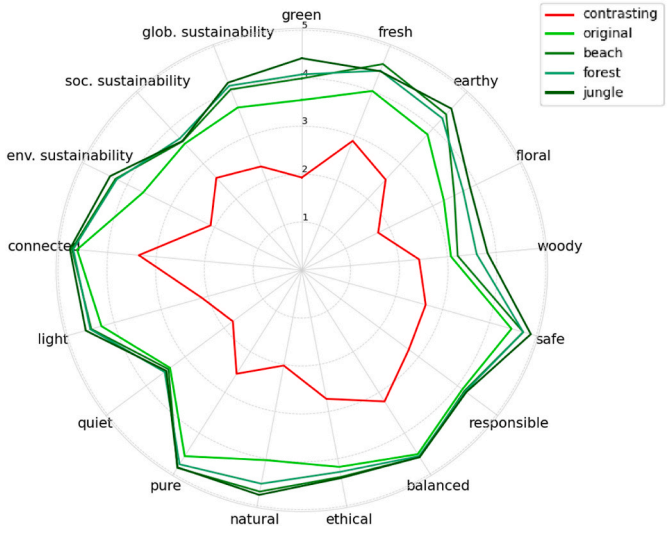

Fig. 2. Mean scores on sustainability descriptors of the four versions of "sustainable" soundtracks and the "contrasting" soundtracks in Study 1.

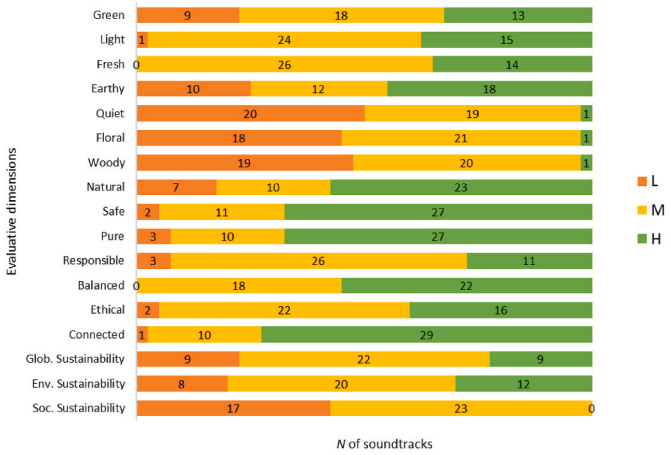

Fig. 3. Absolute frequencies of "sustainable" soundtracks scoring low (L), moderate (M), and high (H) across evaluative dimensions in Study 1. Stimuli were classified as moderate (yellow) if the confidence interval included the scale midpoint, low (orange) if the upper bound was below the midpoint, and high (green) if the lower bound exceeded it. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Fig. 4 offers a closer look at the sustainability rating levels across the soundtracks. The most "sustainable" soundtracks (S1 – S10) were rated moderate to high in global and environmental sustainability. Soundtracks S3, S4, and S7 were the exceptions, with only low to moderate ratings in these dimensions. Additionally, the social sustainability dimension garnered low to moderate ratings across the ten "sustainable" soundtracks. As expected, the "contrasting" soundtracks (C1 – C5) were rated low across all sustainability dimensions.

6.2.2. Original and overlaid versions (beach, forest, jungle) of "sustainable" soundtracks

A significant main effect of the soundtrack version was found for global sustainability ratings, $F(3, 705) = 9.88$, $p < .001$, $\eta_p^2 = 0.04$. Pairwise comparisons showed that the original soundtracks were rated significantly lower than the jungle ($p < .001$), beach ($p = .002$), and forest ($p < .001$) versions, with no significant differences between the overlaid versions. A main effect of the version was also found in environmental ratings, $F(3, 705) = 16.05$, $p < .001$, $\eta_p^2 = 0.06$. Again, this effect was driven by the gap between the original and overlaid versions (all $p < .001$). No main effect of the soundtrack version was observed in the ratings of social sustainability, $F(3, 705) = 0.62$, $p = .606$, $\eta_p^2 = 0.00$ (Fig. 5).

6.3. Interim discussion

The findings of Study 1 supported the methodology outlined in Sections 4 and 5 in two key ways. First, the participants identified the sensory and affective attributes the soundtracks aimed to convey. Second, soundtracks with psychoacoustic properties that best reflected these sensory and affective features received higher ratings in the sustainability dimensions (e.g., S6; see Fig. 4). Additionally, overlaying natural sounds onto sustainability-related soundtracks increased associations with the sustainability concept and its environmental dimension, likely because natural soundscapes evoke environmental ideas and feelings (Spendrup et al., 2016). Notably, this effect was not observed for social sustainability, which consistently received lower scores. With this in mind, we developed a second study exploring potential acoustic expressions of social sustainability.

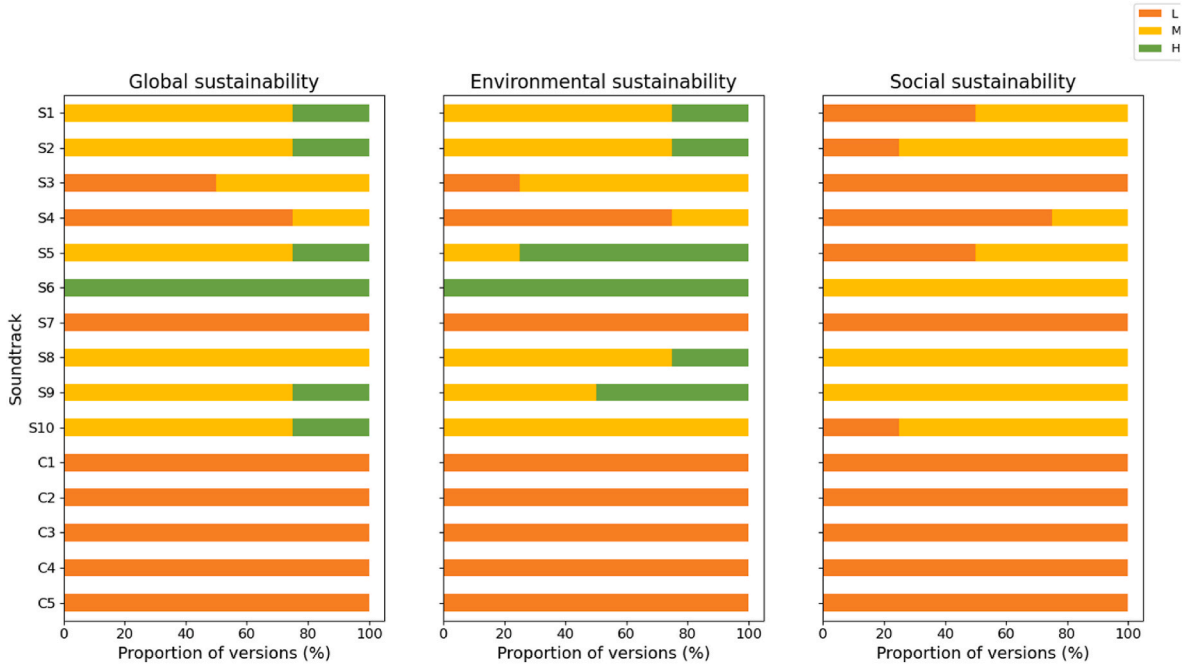

Fig. 4. The proportion of low (L), moderate (M), and high (H) norming levels for different soundtracks across the corresponding versions in global, environmental, and social sustainability dimensions in Study 1. Stimuli were classified as moderate (yellow) if the confidence interval included the scale midpoint, low (orange) if the upper bound was below the midpoint, and high (green) if the lower bound exceeded it. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

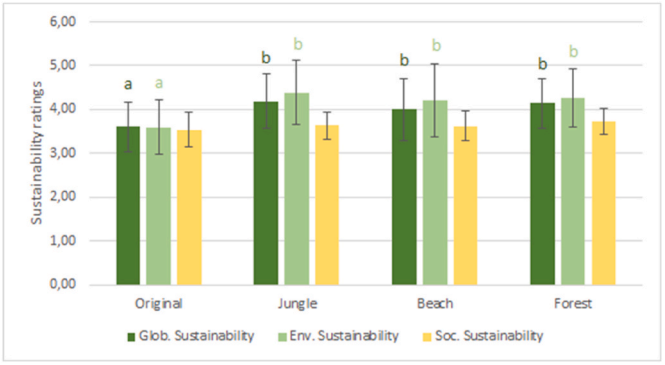

Fig. 5. Comparisons between mean ratings of original, jungle, beach, and forest "sustainable" soundtracks across sustainability dimensions.
Note. Letters a and b denote significant differences between soundtrack versions ($p < .050$).

7. Study 2: the sound of social sustainability

Study 2 aimed to enhance the association between the selected soundtracks and social sustainability perceptions. Therefore, we created three new versions of each "sustainable" soundtrack by adding overlays of human group sounds (i.e., cheering, conversation, and laughing). A new pool of participants assessed these new versions and the original soundtracks across sensory and affective descriptors of sustainability.

7.1. Materials and methods

7.1.1. Participants and design

Two-hundred and fifty-seven participants aged 18–65 ($M_{age} = 38$; $SD_{age} = 11$ years; 56.8 % male, 40.5 % female, 1.6 % non-binary, 1.1 % preferred not to answer) were recruited from Clickworker (https://www.clickworker.com/) and received the same compensation as participants in Study 1.

7.1.2. Materials

The pool of soundtracks for this study included four versions of each of the ten "sustainable" soundtracks (original plus three overlaid versions), as well as the five "contrasting" soundtracks, indicated in Section 5. The overlaid versions of the "sustainable" soundtracks were produced by layering different soundscapes inspired by human group activities. This approach was informed by research demonstrating the effect of implicit and explicit social presence on prosocial behavior (Wang & Dai, 2020) and human conversations layered over music showing higher levels of comfort and preference compared to conversations overlaid on other soundscapes like bird and traffic sounds (Yang & Kang, 2023). Three themes were selected to represent distinct social environments and moods: cheering (characterized by a crowd chanting and applauding), conversation (indistinct, layered speech from a small group of women), and laughing (a small group of people laughing while chatting). All soundtracks were professionally edited following the same guidelines as in Study 2 and lasted 60 s. The final set comprised 45 soundtracks, including the original "sustainable," their three overlaid versions, and the five "contrasting" soundtracks, all of which are publicly available at osf.io/x3gsp/.

7.1.3. Procedures

The procedures, measures, and data analysis were the same as in Study 1, with the overlaid versions of the "sustainable" soundtracks being those described in the Materials subsection.

7.2. Results

The mean scores on the sustainability descriptors revealed a notable difference between the "sustainable" soundtracks and the "contrasting" ones (Fig. 6). A significant main effect of the soundtrack category was found across global, environmental, and social sustainability ratings, $F(3, 254) = 60.27$, $p < .001$, $\eta_p^2 = 0.42$. Pairwise comparisons showed that the original soundtracks were rated significantly higher than the contrasting ones in all three measures (all $p < .001$).

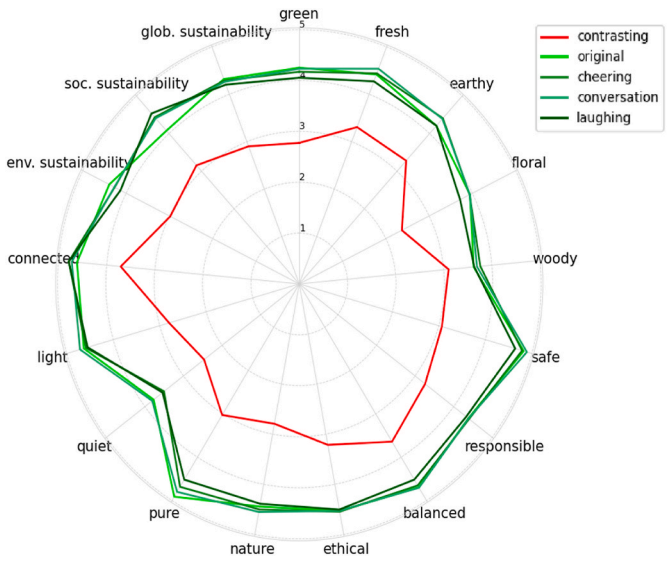

Fig. 6. Mean scores on sustainability descriptors of the four versions of "sustainable" soundtracks and the "contrasting" soundtracks in Study 2.

7.2.1. Norming data

The complete normative data are provided as supplemental material (see Supplementary File 2 at https://osf.io/uhcdn). Fig. 7 shows the distribution of soundtracks across low, moderate, and high levels of all evaluative dimensions. All soundtracks were rated moderate or high in global and social sustainability, while one soundtrack scored low in environmental sustainability. Across the sensory and affective dimensions, the soundtracks were most commonly rated moderate or high. Nonetheless, *quiet*, *floral*, and *woody* had more soundtracks rated low than the rest of the descriptors.

Fig. 8 offers a closer look at the sustainability rating levels across the soundtracks. Almost all "sustainable" soundtracks were rated moderate to high in global, social, and environmental sustainability. However, S7 was an exception, with moderate to low ratings in these dimensions. As anticipated, the "contrasting" soundtracks (C1 – C5) were generally rated low across all sustainability dimensions, except for C3 and C4, which received moderate ratings in social sustainability.

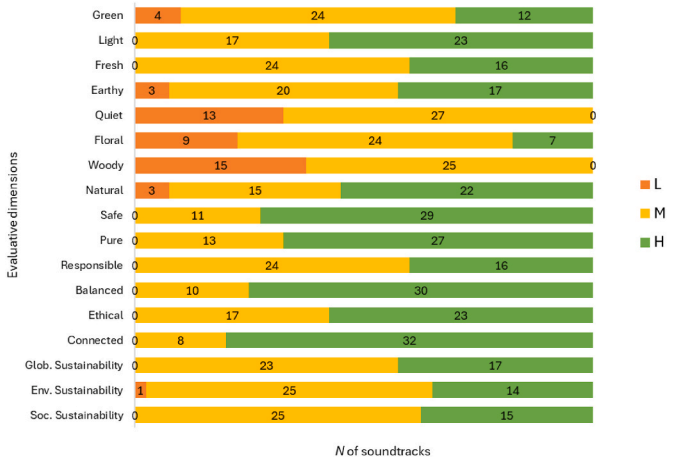

Fig. 7. Absolute frequencies of "sustainable" soundtracks scoring low (L), moderate (M), and high (H) across evaluative dimensions in Study 2. Stimuli were classified as moderate (yellow) if the confidence interval included the scale midpoint, low (orange) if the upper bound was below the midpoint, and high (green) if the lower bound exceeded it. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

7.2.2. Original and overlaid versions (cheering, conversation, laughing) of "sustainable" soundtracks

A significant main effect of the soundtrack version was found for social sustainability, $F(3, 768) = 11.41$, $p < .001$, $\eta_p^2 = 0.04$, and environmental sustainability ratings, $F(3, 768) = 2.75$, $p = .042$, $\eta_p^2 = 0.01$. The three overlaid versions received significantly higher social sustainability ratings than the original (all $p < .001$). Pairwise comparisons also revealed that the original soundtracks were perceived as having a stronger association with environmental sustainability than the laughing versions ($p = .029$). Notably, no significant main effect was observed for global sustainability ratings, $F(3, 768) = 0.76$, $p = .518$, $\eta_p^2 = 0.00$ (Fig. 9).

7.3. Interim discussion

Study 2 replicated the findings of Study 1, with the "sustainable" soundtracks receiving higher ratings than the "contrasting" ones across most sensory and affective descriptors, as well as in the global sustainability and its environmental and social dimensions (e.g., S6 and S8; see Fig. 8). Additionally, overlays of diverse human group sounds on the sustainability-related soundtracks enhanced associations with the social sustainability concept. These overlays did not generally influence global and environmental sustainability ratings (Fig. 9). These findings are pioneering in revealing that human group sounds, when layered over soundtracks with psychoacoustic properties aligned with sensory and affective sustainability descriptors, specifically reinforce associations with the social dimension of sustainability.

8. General discussion

This work was the first to systematically identify and test soundscapes that empirically elicit perceptions of sustainability, as a holistic concept and in terms of its distinct dimensions and concrete descriptors, extending prior existing research. Our approach first identified key sensations and emotions associated with the concept of sustainability, which were then translated into sound and musical elements embedded into soundtracks. Then, testing 70 musical soundtracks across two independent samples showed that music can communicate the abstract and multidimensional concept of sustainability (Barone et al., 2020; Purvis et al., 2019).

The norming data indicated that the selected soundtracks evoked most of the sensory and affective descriptors associated with sustainability (H1), especially when compared to soundtracks portraying contrasting elements (e.g., high *vs.* low pitch). Additionally, overlaid soundtracks (i.e., soundscapes), including natural and human group sounds, further enhanced associations with the environmental (H2; Study 1) and social (H3; Study 2) dimensions, respectively. This suggests that musical features can be combined with meaningful, everyday sounds to evoke specific conceptual associations.

While the translation of the sensory and affective attributes into psychoacoustic parameters resulted in meaningful differences between the sustainable and the contrasting soundtracks, there were also stimuli that did not perfectly align with the overall pattern of results. For instance, Soundtrack S7 consistently received low sustainability ratings, regardless of the sound overlay (see the norming data of Study 1). This outcome suggests that certain musical parameters may not effectively evoke sustainability-related associations, even when paired with more concrete auditory cues provided by the overlays. These soundtracks may have evoked other conceptual associations (i.e., referential meanings) that could be inconsistent with the sustainability concept (e.g., synthetic elements, futuristic ambience).

The results of Study 1 demonstrated that adding natural sounds not only increased ratings in the environmental dimension but also global sustainability ratings. Conversely, the addition of human group sounds in Study 2 had a more specific impact on social sustainability ratings and did not extend comparably to the global sustainability concept. This

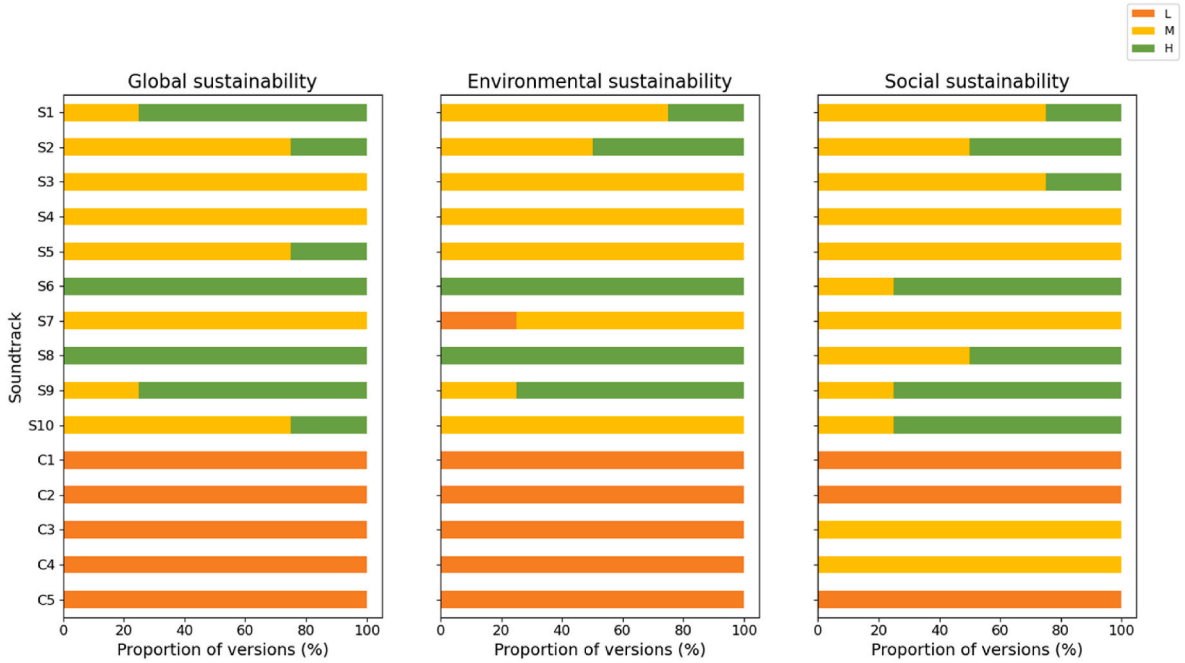

Fig. 8. The proportion of low (L), moderate (M), and high (H) norming levels for different soundtracks across the corresponding versions in global, environmental, and social sustainability dimensions in Study 2. Stimuli were classified as moderate (yellow) if the confidence interval included the scale midpoint, low (orange) if the upper bound was below the midpoint, and high (green) if the lower bound exceeded it. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

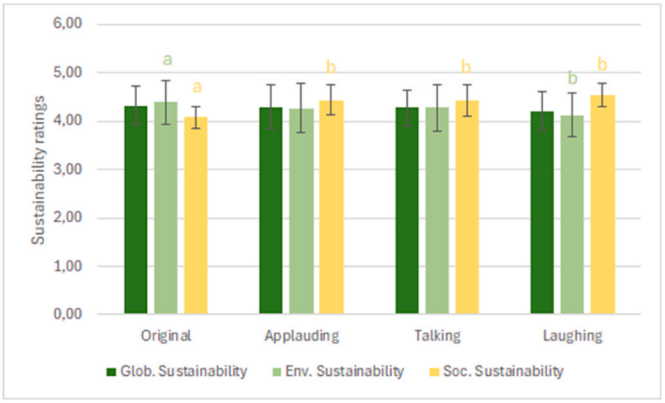

Fig. 9. Comparisons between mean ratings of original, applauding, talking, and laughing, "sustainable" soundtracks across sustainability dimensions.
Note. Letters a and b denote significant differences between soundtrack versions ($p < .050$).

result may reflect the strong emphasis placed on environmental factors within the concept of sustainability. Supporting this interpretation, Damico et al. (2022) found that when participants were asked to report words they associated with sustainability, 70 % mentioned environmental terms, whereas only 20 % of respondents spontaneously mentioned the social dimension. Therefore, sensory cues linked to environmental aspects may more readily activate the broader sustainability concept in individuals' minds than those associated with social aspects.

8.1. Implications

Research on sustainability nudging has given scarce attention to auditory stimuli while typically addressing only its environmental dimension (e.g., Esteky, 2021; Hallez et al., 2023; Motoki et al., 2024; Sucapane et al., 2021; Techawachirakul et al., 2023). In contrast, this work revealed the differential effects of soundscapes on perceptions of environmental and social sustainability. This contribution advances the theoretical understanding of sustainability as a holistic concept that integrates both dimensions within individuals' minds, illustrating how they conceptualize and distinguish between them (Sheth et al., 2011). This nuanced approach could strengthen organizations' communication strategies (e.g., sound in sustainable branding), such as in shaping perceptions of corporate social responsibility (Oberseder et al., 2013), by showing the potential for sound to evoke responses related to social and environmental issues. In line with United Nations Sustainable Development Goal 12, which aims to reshape production and consumption patterns to respect ecological limits and promote social equity (United Nations, 2015), soundscapes could be an alternative tool for nudging sustainable behaviors across communication campaigns and policy-making initiatives.

Different non-musical elements (nature and human group sounds) layered over sustainable-themed instrumental music can selectively enhance associations with environmental or social sustainability. Consistent with Truax (1984, pp. 42–56), who proposed that music, environmental, and human-generated sounds are systems of acoustic communication, the empirical use of non-musical sound elements associated with concrete descriptors of an abstract concept provides a specific understanding of these elements in acoustic communication. Therefore, fusing them with music can convey not only broad concepts but also distinguish between closely related sub-concepts, revealing a new level of semantic precision in musical communication.

This research demonstrates that carefully selected soundtracks, chosen for their specific sound elements, can ground abstract concepts like sustainability through sensory and affective crossmodal correspondences. While previous work has shown that instrumental music can modulate sensory and affective perceptions (Guedes et al., 2023) and abstract ideas related to brand personality (Melzner & Raghubir, 2023), our findings extend this line of research by revealing music's capacity to shape perceptions of an abstract, multifaceted concept. In doing so, the study extends grounded cognition theory by illustrating

how auditory stimulations help listeners connect concrete perceptual cues with higher-level cognitive associations along the concreteness–abstractness continuum (Reinboth & Farkaš, 2022). It also aligns with spreading activation theory in semantic memory, as soundscapes linked to concrete sustainability descriptors can indirectly activate broader abstract dimensions (i.e., social and environmental), showing that sensory and affective congruency provides an indirect pathway to conceptual activation. By integrating these perspectives, this research advances our understanding of how music delivers meaning.

Adding to previous work demonstrating that natural soundscapes encourage environmentally sustainable choices (Esteky, 2021; Spendrup et al., 2016; Zandstra et al., 2025) and pro-environmental attitudes (Zelenski et al., 2015), Study 1 highlights the importance of the combination of natural soundscapes with sustainability-related music in eliciting perceptions of environmental sustainability and most of its descriptors (e.g., *fresh*, *balanced*, *safe*, *pure*). Previous work also indicated the positive effects associated with this combination, facilitating simultaneous increases in affective indicators toward a nature-related experience (perceived restorative potential, calmness, and excitement) compared to music-only or nature-only auditory conditions (Smalley et al., 2023). This successful combination provides a theoretical foundation for using nature sounds in sonic branding development to enhance environmental sustainability perceptions.

Enhancing social sustainability perceptions through human group sounds layered over soundtracks contributes to previous findings on prosocial behavior nudging. Research has demonstrated that music with prosocial lyrics can encourage behaviors such as fair-trade purchasing, cooperation, donating, and reducing aggression (e.g., Greitemeyer, 2009a, 2009b; Ruth, 2017). Similarly, emotion-inducing music (e.g., happy, chill, inspiring) has been shown to promote such actions (Chang & Kim, 2022; Fukui & Toyoshima, 2014; Kniffin et al., 2017). Study 2 suggests that human group sounds combined with music, lacking explicit prosocial content, may still evoke associations with social sustainability. These findings extend research on the prosocial effects of music to the impact of soundscapes in the context of social sustainability.

This work provides support to the call for more research on auditory elements in marketing (Knoeferle & Spence, 2021; Krishna, 2012) by demonstrating how sound can match abstract concepts through sensory and affective descriptors—an approach still underexplored in sonic branding (Spence & Keller, 2024). By leveraging sound design, brands across various sectors can enhance customer experiences at multiple touchpoints, reinforcing sustainability values and fostering deeper connections with environmentally and socially conscious consumers. A practical application in the food and beverage industry, for instance, involves reshaping the multisensory environment where food is selected and consumed to encourage sustainable choices (Cardello & Meiselman, 2018; Zandstra et al., 2025).

With the growing popularity of online shopping (Sellers Commerce, 2025), communicating sustainability through sound becomes critical to building product expectations due to the limitations of the current digital experiences. Since emotional trust plays a crucial role in online purchase intention (Wu et al., 2023), brands might feel encouraged to use sustainable-themed soundtracks, creating immersive experiences that engage consumer emotions. Physical stores selling sustainable products could also use targeted soundscapes within their atmospherics to reinforce brand values and influence consumer perceptions. Sonic logos can incorporate nature or human group sounds along with instrumental sounds to reinforce their sustainability credentials (Spence & Keller, 2024; Techawachirakul et al., 2023). Particularly, small and medium-sized enterprises can leverage these findings in cost-effective ways to provide unique sensory experiences that differentiate them from larger competitors.

Companies must exercise caution and responsibility when employing sustainability-related soundscapes in communication plans, as evidence shows that nature-evoking sounds can mislead consumers into perceiving products as environmentally friendly, regardless of their actual environmental impact (i.e., "executional greenwashing effect"; Parguel et al., 2015). To avoid this, businesses must align their sonic branding with their actual sustainability performance, incorporating transparent information such as visual environmental labels to mitigate misleading impressions (Parguel et al., 2015; Spendrup et al., 2016). Authenticity is crucial, as deceptive sustainability claims can damage a company's perceived ethical integrity, reducing purchase intention (Fella & Bausa, 2024; Magnier & Schoormans, 2015). In alignment with these concerns, the European Union's Green Claims Directive mandates that explicit environmental claims must be substantiated with verifiable scientific evidence (European Commission, 2023). Similarly, policymakers should regulate the use of auditory nudges, establishing guidelines to ensure that sustainability-related sounds are used transparently and ethically. This framework can protect consumers from misleading claims while promoting authentic sustainability efforts and fostering the responsible use of sound to encourage more sustainable consumer choices.

8.2. Limitations and future directions

While we envision that this stimulus set (and other stimuli developed from this framework) may hold the potential to shape individual behavioral experiences, this remains speculative at present (Zandstra et al., 2025). Specifically, research involving products will be needed to test whether the observed perceptual associations translate into consumer choices or experiences. Longitudinal designs, in particular, may help capture whether such effects lead to lasting behavioral change.

One innovative aspect of the approach presented in this paper is the possibility of distinguishing between the interrelated facets of social and environmental sustainability. While this likely adds versatility and differentiation in the application of the stimuli, other facets of sustainability (e.g., economics; Purvis et al., 2019) were not accounted for in the present research.

Our findings also indicate that the overlay of concrete sounds over the musical soundtracks adds value to the music presented alone, with small to medium effect sizes observed. However, whether the combination of music and concrete sounds surpasses the value of concrete sounds presented alone remains undetermined. While this question warrants exploration in future research, the present work focused on musical stimuli for two key reasons. First, the abstract nature of musical parameters offers greater flexibility, enabling the creation of an infinitely diverse range of novel stimuli through various combinations of these parameters. Second, music stimuli are naturally embedded in many decision-making contexts (e.g., background soundscapes in retail or hospitality settings). Their subtle association with sustainability makes them particularly well-suited to shaping sustainability experiences in a more natural and impactful manner.

One limitation of the present study is the restricted number of soundtracks included, which, while diverse in its choice of genre and instrumentation, do not allow for a systematic manipulation of specific psychoacoustic parameters. The music stimuli were retrieved from pre-existing compositions rather than being generated with a controlled variation in specific musical features (cf. Wang et al., 2017). Consequently, there was no consistent pattern in instrumentation or style across the songs, limiting the possibility of drawing broader conclusions about their perceptual coherence. Advancements in generative artificial intelligence now offer the possibility of creating future music stimuli that differ only in parameters directly related to sustainability perception (see Table 3), while keeping other musical attributes fully customizable to user preferences. Such an approach could enhance experimental control, providing deeper insights into the role of specific auditory features in shaping sustainability-related experiences.

Additionally, the online data collection procedures introduced limitations in terms of control over the conditions of sound delivery. Although participants were instructed to set the volume to a comfortable

level before initiating the listening task and underwent control items to ensure the use of headphones, differences in perceived loudness may still have occurred across soundtracks due to psychoacoustic variability. This limitation arises from both the intrinsic loudness perception characteristics of the audio stimuli and the variability in playback conditions, including the type of headphones and listening environment used by participants. Finally, the use of different recruitment platforms across studies may have further introduced minor sample variability, despite consistent demographic selection criteria and compensation.

9. Conclusions

This paper introduces a new framework for developing and using soundscapes to communicate sustainability. It identifies key sensory and affective descriptors linked to sustainability and translates them into musical features. These data informed the development of a validated set of soundtracks for future research and practical applications. Importantly, nature sounds over these soundtracks boosted environmental perception, while overlaid human group sounds boosted social perception. As sustainability plays an increasingly significant role in consumer decision-making, the multisensory context could help deliver more impactful and differentiated messages (Fenko et al., 2016; Zandstra et al., 2025). Future research should examine how auditory elements shape perceptions, judgments, and behaviors related to sustainability, offering a foundation for innovative strategies (e.g., sensory nudges) to encourage more sustainable consumption and practices.

CRediT authorship contribution statement

Brayan Rodríguez: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **David Guedes:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **João Graça:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Luis H. Reyes:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Margarida Vaz Garrido:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Marília Prada:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Felipe Reinoso-Carvalho:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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