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Hierarchical pattern analysis of tourist environmental compensation: Evidence from the Canary Islands

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ABSTRACT

This study applies a hierarchical pattern analysis to examine how tourists' carbon offset willingness intersects with behavioural profiles. Using FP-Growth on data from nearly 80,000 visitors to the Canary Islands (2022–2023), it shows that carbon offsetting is shaped not only by environmental values but also by cognitive engagement, planning autonomy, and dependence on mass-tourism infrastructures. The analysis identifies four tourist profiles, from non-compensators with routinized behaviours to highly proactive tourists integrating sustainability into their consumption. The study proposes targeted policies such as opt-out defaults, symbolic eco-incentives, loyalty schemes, and participatory governance. Findings highlight the need for multi-layered sustainability strategies that move beyond binary classifications of environmental commitment.

1. Introduction

The tourism industry plays a key role in the global economy, driving mainly GDP and creating jobs around the world (WTO, 2025). It has demonstrated remarkable resilience, especially in island areas, where tourism is often the main economic driver. The combination of rising international travel and travel democratization has resulted in record-breaking tourist arrivals worldwide, according to the WTO (2025), before the COVID-19 pandemic and after its recovery. Within this context, islands have gained popularity as tourist destinations because they provide distinctive experiences that unite natural beauty with cultural heritage (Parra-López & Martínez-González, 2018).

However, the rapid expansion of island tourism has created growing doubts about its long-term sustainability (Gössling, 2002). The environmental stressors of ecosystem degradation and high resource consumption affect coastal and island regions particularly strongly (Sharpley, 2020). Against this backdrop, understanding how different tourist segments perceive environmental responsibility and act upon it is crucial for destination management (Dolnicar & Leisch, 2008; Lee & Jan, 2018). Studying tourists' carbon offset willingness is especially relevant because it provides a graded attitudinal indicator of pro-environmental engagement, linking stated dispositions to concrete consumption choices and avoiding simplistic binary classifications such as green/non-green labels.

This perspective also resonates with established behavioural theories such as the Theory of Planned Behaviour (Ajzen, 1991) and the Value-Belief-Norm model (Stern, 2000), which explain how environmental values, attitudes, and perceived behavioural control interact to shape sustainable choices. By grounding offset willingness in these frameworks, our study connects stated intentions to deeper motivational structures and translates them into actionable behavioural categories. As a policy lever, offsetting can be incorporated into booking and packaging systems, transparently channel resources toward conservation, and serve as an evaluable metric for tiered interventions. Placing offset willingness at the core of our framework, therefore, enriches behavioural analysis and offers destination managers a practical instrument to accelerate sustainability transitions.

Although the study of tourist environmental sustainability behaviour has received extensive research, three major limitations persist in the literature. First, the current research on environmental commitment uses a single-dimensional approach, which fails to capture the complex relationships between environmental awareness levels and tourist behaviour. Second, despite previous research on tourist spending in island destinations (Eugenio-Martin & Inchausti-Sintes, 2016; Gómez-Déniz et al., 2020), the relationship between spending patterns and environmental compensation behaviours across different tourist segments remains poorly understood. Third, traditional methodological approaches have failed to uncover the intricate hierarchical patterns

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linking environmental commitment and tourist decision-making because they concentrate on isolated factors influencing environmental behaviour.

To bridge these gaps, we relate tourists' carbon offset willingness to behavioural factors: consumption habits, activity choices, and planning formats. Using nearly 80,000 observations from visitors to the Canary Islands (2022–2023), we develop and validate a novel Hierarchical Association Rules (HAR) framework combining the Frequent Pattern Growth (FP-Growth) algorithm with a three-stage analytical strategy. The framework translates stated intentions into management-ready segments aligned with engagement levels, supporting the design of environmental initiatives and the tailoring of marketing, policy, and experience design to different degrees of environmental commitment.

Although analyzed in the Canary Islands, the behavioural architecture and four-segment tourist typology generalize to many tourism-intensive destinations with similar structures: air-dependent access, coastal concentration, packaged products, and fragile ecosystems. By linking offset willingness to observed consumption choices, the typology offers a transferable diagnostic that can be adapted to local contexts and used to position demand-side instruments alongside supply-side decarbonization in the sustainability transition.

Under the presented background, this study addresses the following research questions:

RQ1. How does tourists stated willingness to offset carbon emissions relate to observable patterns of consumption, activity choice, and travel organization?

RQ2. To what extent does carbon offset willingness reveal internally heterogeneous behavioural configurations that go beyond traditional single-dimensional segmentation approaches?

RQ3. Can a Hierarchical Association Rule framework (HAR) uncover nested and multi-level behavioural structures that conventional clustering and regression-based methods fail to detect?

By answering these questions, the study makes three core contributions to sustainable tourism research: (i) it establishes and empirically validates a hierarchical behavioural framework that links levels of environmental commitment to distinct consumption patterns, revealing that the attitude–behaviour gap operates as a heterogeneous and threshold-dependent phenomenon rather than a uniform distance between intention and action; (ii) it advances methodology by applying association-rule mining (FP-Growth algorithm) (Agrawal et al., 1993) to tourism data, capturing multi-level co-occurrence structures often missed by conventional models; and (iii) leveraging a large-scale visitor dataset, it shows how willingness to carbon-offset maps onto actionable segments, turning stated intentions into profiles that inform strategy and policy.

In the next sections, we present the literature framework that guided our work (*Section 2*), detail our methodological approach (*Section 3*), and outline the key descriptive statistics before moving into a three-level analysis of tourist segments (*Section 4*). We then discuss the broader implications of our findings for sustainable tourism management (*Section 5*) and conclude with reflections on limitations and future research directions (*Section 6*).

2. Literature review

2.1. Tourism sustainability challenges

Tourism has emerged as one of the fastest-growing economic sectors, but its expansion carries substantial environmental costs. Lenzen et al. (2018) warn that the sector's contribution to global greenhouse gas (GHG) emissions will intensify if current trends persist, underscoring the need for context-specific sustainability strategies.

Empirical research on tourism and environmental quality yields mixed results across contexts. Ciarlantini et al. (2023) found no support for the Environmental Kuznets Curve (EKC) hypothesis in five Southern European countries, questioning the assumed link between tourism-driven growth and pollution reduction. Zhao et al. (2023) corroborate this context-dependence through panel data analysis across Chinese provinces, finding weak coupling between tourism activity and air quality. Meta-analyses have helped compile extensive research on the environmental impact of tourism. Segarra et al. (2024) examined 105 studies, finding tourism drives both economic growth and environmental damage, highlighting the need for comprehensive, data-driven research addressing sustainable tourism complexity.

While policy instruments remain essential, tourism sustainability also relies on tourists' active involvement in minimizing their environmental footprint. However, prior studies reveal wide variation in tourist responses to sustainability initiatives. Raffaelli et al. (2022) observed tourist reluctance to pay for greener alternatives in Italy, while McLennan et al. (2014), found significant variations in carbon offsetting willingness based on national origins, with Europeans showing higher participation than Asians. Despite increasing environmental sensitivity (Di Giusto et al., 2018), voluntary offsetting schemes remain insufficient for substantial impact mitigation (Gössling et al., 2007).

Given these limitations, green taxation has gained relevance. Zhang et al. (2023) found environmental taxes effective for reducing air pollutants in China but limited for wastewater and solid waste, while Durán-Román et al. (2021) observed low demand sensitivity to moderate tax increases in Spain, suggesting room for well-calibrated fiscal instruments. Circular economy principles have simultaneously become central to sustainable tourism strategies (Bosone & Nocca, 2022).

2.2. Sustainable tourist behaviour in island tourism

According to the literature on island destinations, a growing body of research has examined tourism from both behavioural and structural sustainability perspectives across diverse insular contexts. In the case of the Balearic Islands (Spain), Palmer and Riera (2003) analyze tourists' willingness to pay for an environmental tax designed to mitigate the negative externalities generated by mass tourism. Their findings reveal that a substantial proportion of visitors are willing to accept the introduction of an ecotax, particularly when the revenues are explicitly allocated to environmental protection. This evidence supports the effectiveness of price-based policy instruments as mechanisms to internalize environmental costs in highly seasonal and resource-constrained island economies.

Complementing these fiscal and strategic perspectives, vulnerability-based approaches offer an ecological assessment of tourism pressures. In the Indonesian context, Kurniawan et al. (2019) develop a Small Island Vulnerability Index (SIVI) to evaluate tourism-induced biophysical stress in the Gili Matra Islands. Their results indicate vulnerability levels, with tourism identified as the principal stressor through processes such as coastline erosion, coral reef degradation, live coral loss, and the spatial expansion of built-up areas. The study demonstrates that, even when tourism generates significant economic benefits, intensive marine and coastal use may push small island ecosystems toward critical ecological thresholds.

Beyond the Spanish and Indonesian cases, Lin et al. (2025) investigate environmentally responsible tourist behaviour in Jeju Island (South Korea), a UNESCO-recognized volcanic island facing mounting ecological pressure due to increasing tourist inflows. By integrating the Value-Identity-Personal Norm (VIP), Value-Attitude-Behaviour (VAB), and Theory of Planned Behaviour (TPB) frameworks, the authors demonstrate that pro-environmental conduct is shaped by a combination of values, environmental identity, personal norms, and perceived behavioural control. The Jeju case underscores that sustainable tourist behaviour in island destinations is driven by interacting psychological determinants rather than isolated attitudinal variables, highlighting the multidimensional nature of behavioural sustainability.

Moving to the Canary Islands (one of Europe's most tourism-

intensive outermost regions), the academic literature has traditionally focused on expenditure patterns and economic performance (Eugenio-Martin & Inchausti-Sintes, 2016; Gómez-Déniz et al., 2020). Alongside these are more controversial contributions reflecting the mounting pressures experienced by the region in recent years. In this context, Sánchez-Bayón and Daumann (2025) interpret tourismphobia in the Canary Islands through a structural-cognitive framework, linking housing market tensions, infrastructure congestion, and governance imbalances to the erosion of tourism's social legitimacy.

Nevertheless, earlier strategic reflections on island sustainability are found in García-Falcón and Medina-Muñoz (1999), focusing on Gran Canaria Island. Their analysis stresses that tourism competitiveness in island contexts cannot be dissociated from environmental management and long-term resource preservation. They argue that strategic planning, institutional coordination, and environmental quality constitute fundamental pillars for sustaining island tourism models, particularly in mature mass-tourism destinations.

Moreover, increasing scholarly attention has been devoted to congestion externalities and the design of sustainability-oriented policy instruments. López-del-Pino and Grisolía (2017) estimate tourists' willingness to pay for congestion reduction in sun-and-beach destinations, identifying a measurable demand for improvements in environmental quality and reduced overcrowding. In a related contribution, López Del Pino et al. (2021) show that moderate accommodation taxes (ranging between €1 and €2 per night) are associated with limited reductions in tourism demand when revenues are transparently earmarked for environmental conservation and heritage protection.

2.3. Tourism segmentation approaches

In regard to tourist segmentation, it has traditionally focused on identifying groups based on common characteristics such as expenditure patterns, motivations, and demographic factors (Ferreira & Perks, 2022). Specifically, segmentation efforts have placed significant emphasis on expenditure patterns, highlighting diverse tourist profiles and their economic impact on destinations. For instance, as a characteristic case, Leones et al. (1998) demonstrated that birdwatchers visiting Arizona exhibited notably high spending habits.

In mature island destinations, expenditure-based segmentation has been used as a central analytical tool to identify heterogeneous demand structures. In the Balearic Islands, Pérez and Juaneda (2000) apply cross-sectional regression models to segment tourists according to expenditure levels, distinguishing between spending at origin and at destination, and showing that demographic, socioeconomic, and trip-related characteristics define clearly differentiated spending profiles. Similarly, for the Canary Islands, Díaz-Pérez et al. (2005) explicitly adopt an expenditure-segmentation approach, using decision-tree analysis to classify tourists into homogeneous groups based on daily on-destination spending and to identify the segments associated with higher economic returns.

While expenditure-based segmentation dominated early approaches, more recent research has sought to connect segmentation efforts with sustainability objectives, recognizing the critical role that differentiated tourist attitudes play in advancing sustainable practices. For example, Marin et al. (2021) showed that destination image strongly influences the attraction of environmentally conscious tourists, while Zuo et al. (2023) highlighted the potential of shifting promotional strategies toward sustainability-oriented narratives.

However, much of this literature still relies on aggregated or self-reported measures of willingness to act, which often obscure within-group heterogeneity. Dolnicar and Leisch (2008) emphasized the methodological need to account for behavioural heterogeneity in segmentation; Higham and Cohen (2011) documented tourists' reluctance to participate in voluntary carbon offsetting schemes; and Raffaelli et al. (2022) illustrated the importance of profiling tourists with respect to environmental values and willingness to act.

Yet these contributions remain largely anchored in attitudinal perspectives and linear models of intention, failing to connect stated environmental commitment with observable behavioural patterns. Our study responds directly: examining how carbon offset willingness relates to actual consumption, activity, and travel organization choices (RQ1), and whether it reveals internally differentiated and hierarchically structured behavioural configurations (RQ2).

2.4. Innovative methods for tourism analysis

In parallel with these practical applications, recent methodological advancements have introduced innovative analytical approaches, particularly those grounded in machine learning techniques (Tussyadiah, 2020), with a dramatic increase in publications since 2017 (Gössling, 2021). Unlike conventional statistical models such as ordinary least squares, tobit models, or conditional quantile regression frequently employed in earlier tourism expenditure studies (Eugenio-Martin & Inchausti-Sintes, 2016; Thrane, 2014; Zheng & Zhang, 2013), machine learning techniques offer several distinct analytical advantages. These approaches demonstrate superior capacity for handling the highly dynamic and volatile demand patterns characteristic of tourism, addressing heterogeneous data sources, and enabling personalization at scale—challenges that traditional statistical methods struggle to address effectively.

For instance, recent studies have applied convolutional neural networks, deep learning, and sentiment analysis to extract meaningful features from hotel images and online reviews (Núñez et al., 2024), while topic modelling using latent Dirichlet allocation has identified eight distinct research domains in tourism where machine learning techniques are applied, ranging from social media analytics to smart tourism management (Madzík et al., 2023).

Among these advancements, co-occurrence analysis has emerged as an increasingly valuable tool for identifying relationships within tourism data (Ciano et al., 2019; Pestana et al., 2019), though its application has been primarily limited to bibliometric studies rather than behavioural pattern identification.

Notable exceptions include Zhang and Yun (2014), who revealed systematic differences in landscape co-occurrence patterns across Chinese microblogs, and Haris et al. (2020), who extracted spatial co-occurrence information from travel narratives to construct enriched points-of-interest graphs as an alternative to GIS-based approaches. Hernández et al. (2021) extended this line of work by applying exponential random graph models to five years of TripAdvisor data in Madrid, showing that homophily in attraction popularity and category increased over time, suggesting a positive feedback loop between popularity and visits alongside growing specialisation of tourist behaviour.

Extending this line of work, Zuo et al. (2023) applied co-occurrence analysis to destination image formation through space-people-activity attribute analysis in Thailand's promotional videos, revealing how destination marketing organisations construct place attachment through strategic co-occurrence patterns. From a predictive modelling perspective, Luo et al. (2025) developed social network service co-occurrence similarity (SNS-COS) to capture spillover effects in tourism demand forecasting, demonstrating superior performance over traditional geographic similarity measures.

Despite these advancements, co-occurrence analysis has not been systematically extended to individual-level sustainability behaviour. Lithgow et al. (2019) offered a notable exception at the spatial level, demonstrating how such methods can uncover hidden interdependencies between environmental pressures and tourism infrastructure along Mexican coastlines. Yet the behavioural dimension — particularly tourists' willingness to engage in carbon offsetting — remains largely unaddressed, underscoring the need for segmentation approaches capable of capturing multi-layered behavioural patterns linked to sustainability decisions.

In this context, our methodological contribution (integrating the FP-Growth algorithm within a hierarchical segmentation framework specifically applied to carbon offsetting behaviours) directly addresses these analytical gaps. By moving beyond linear and single-dimensional models (Segarra et al., 2024) and advancing the literature on data-driven techniques in tourism (Gretzel et al., 2015; Xiang et al., 2015), the approach represents a novel application of association rule mining to sustainability research (RQ3). It extends existing co-occurrence applications, which have thus far focused primarily on keyword analysis and spatial-environmental linkages, toward the examination of actual behavioural co-occurrence patterns in environmental decision-making contexts.

3. Data and methodology

The Canary Islands represent an especially suitable case for this analysis: as one of Europe's most visited regions (Eurostat, European Commission, Statistical Office of the European Union, 2024), the archipelago combines high tourism intensity with distinct environmental vulnerabilities — territorial insularity, energy-intensive infrastructures, and structural exposure to climate change (Padrón-Fumero et al., 2025) — making it a relevant setting for investigating tourist engagement with compensatory mechanisms (Parra-López & Martínez-González, 2018). Data derived from the Tourist Expenditure Survey (EGT) conducted quarterly by ISTAC during 2022–2023, comprising 78,874 valid responses representing 26.9 million visitors, with sampling weights ensuring population representativeness (Table 1). The sample exhibits substantial heterogeneity: tourists range from 16 to 99 years old (mean = 45.4), trip durations vary widely (mean = 9.0 nights), and total expenditure ranges from budget to luxury profiles (mean = €841; SD = €1687).

The key variable measures tourists' carbon offset willingness through the question: "Would you be willing to spend more on your trip to reduce your carbon footprint?" Respondents selected from five mutually exclusive categories: no willingness (0%), less than 5%, 5–10%, 10–20%, and more than 20% of trip expenditure.

As shown in Fig. 1, 62.7% of tourists express some willingness to compensate, though most (30.3%) would contribute only up to 5% of destination expenses and only 10.5% are willing to pay more than 10% — reflecting a distribution consistent with the behavioural economics literature, where contributions below 5% represent symbolic engagement, 5–20% indicate moderate commitment, and above 20% substantial environmental prioritisation.

Destination expenses included all local spending but excluded international airfare, consistent with EGT survey methodology. The remaining variables are grouped according to the tourist decision-making process and their socioeconomic characteristics. Their full descriptive statistics are presented in *Table A.1* in the appendix:

- Socioeconomic and demographic: age, gender, residence, income level.
- Inspiration and motivation: travel purpose, first visit.
- Destination selection: importance ratings (0–4 scale) of climate, culture, safety, attractions, price, among others.
- Reservation and organization: travel group size, flight costs, stay length, accommodation type, meal plans, island selection.
- Travel experience: destination expenditure per person, daily spending by category, activities performed.
- Experience evaluation: revisit intentions, sustainability perceptions.

Table 1
Sample characteristics and trip patterns.

Variable	Mean	SD	Min	P25	Median	P75	Max
Age (years)	45.42	14.94	16	33	45	57	99
Trip Duration (nights)	9.03	7.99	1	7	7	10	181
Group Size (persons)	2.62	1.47	1	2	2	3	27
Total Spending (€)	840.78	1687.34	67	340	609	1000	4127
Daily Spending (€)	49.79	98.52	1.2	22	40	63	891

Notes: All monetary values in euros.
Source: Own Elaboration.

Three families of methods dominate tourist segmentation research: clustering algorithms (k-means, hierarchical clustering), regression-based models (OLS, Tobit, quantile regression), and latent class analysis (LCA). Clustering algorithms partition tourists into mutually exclusive groups based on variable similarity, which makes it difficult to capture the conditional nature of environmental decision-making — a tourist's activity choices are contingent upon compensation willingness, not independent of it.

Regression-based approaches estimate marginal effects of individual predictors on outcomes such as expenditure or willingness to pay (Eugenio-Martin & Inchausti-Sintes, 2016; Thrane, 2014), but average these effects across the full sample, smoothing over the within-group heterogeneity that our Level 2 and Level 3 analyses reveal as analytically decisive. LCA allows probabilistic assignment to unobserved classes yet requires a priori assumptions about class number and distributional form — assumptions difficult to justify in exploratory analysis of a behavioural construct as novel as carbon offset willingness.

Association rule mining via FP-Growth addresses these limitations directly: it imposes no distributional assumptions, requires no a priori class specification, and captures co-occurrence patterns among behavioural variables within each compensation tier. This enables the identification of configurations — such as aspirational sympathizers and passive compliers within the same offsetting bracket — that are statistically indistinguishable by conventional segmentation yet follow entirely different behavioural logics. The hierarchical extension (HAR) structures these patterns across three nested analytical levels, moving progressively from broad environmental commitment gradients to micro-behavioural configurations in a design that matches the multi-layered nature of the research problem.

The FP-Growth algorithm constructs an FP-tree using a divide-and-conquer strategy to identify meaningful "if-then" associations between behavioural variables. Minimum support (5%) and confidence (60%) thresholds were selected based on established practices in the association rule mining literature. At 5% support, each identified pattern corresponds to approximately 3940 tourists — sufficient to ensure statistical robustness while preserving analytically relevant minority segments (Agrawal et al., 1993).

Lower thresholds risk retaining spurious co-occurrences, while thresholds above 7–8% tend to exclude low-frequency but substantively important environmental segments. A confidence threshold of 60% reflects the goal of identifying meaningful behavioural tendencies rather than near-deterministic rules, consistent with established FP-Growth applications to large behavioural datasets (Han & Pei, 2000).

The HAR framework treats parsimony as an explicit design constraint: each level serves a distinct and non-redundant analytical function. Level 1 establishes the primary segmentation structure based on carbon offset willingness. Level 2 applies FP-Growth within each segment to reveal sub-patterns invisible at the aggregate level. Level 3 identifies micro-behavioural configurations — distinguishing profiles such as aspirational sympathizers from passive compliers — whose motivational structures diverge in policy-relevant ways despite comparable stated willingness. Although the HAR structure could theoretically extend beyond three levels, further granularity would compromise managerial interpretability without altering the substantive conclusions. The three-level structure thus represents the point at which additional analytical depth ceases to generate proportional interpretive gain.

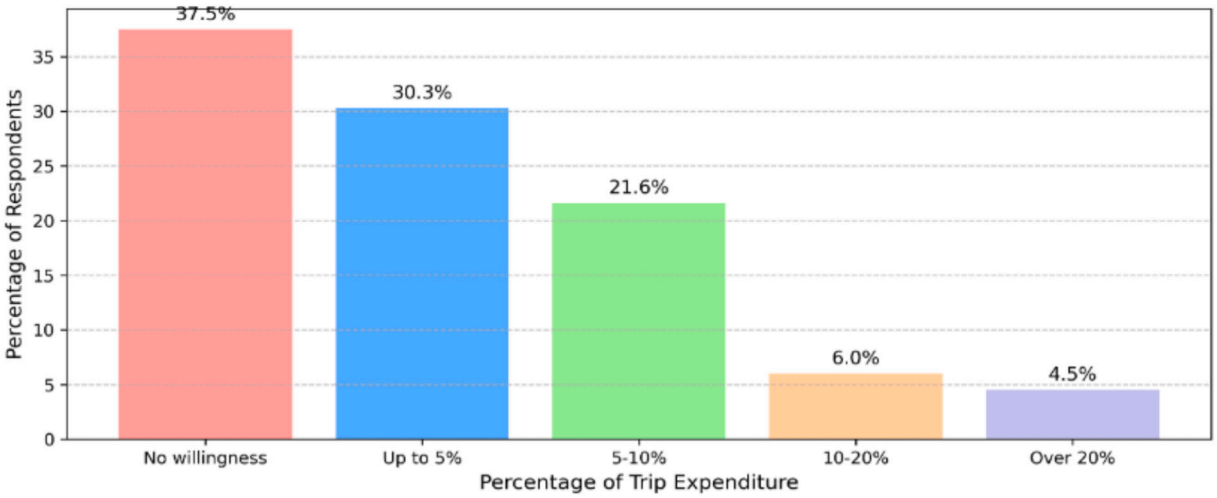

Fig. 1. Distribution of willingness to offset carbon emissions.
Source: Own Elaboration.

3.1. Frequent pattern growth algorithm

The *Frequent Pattern Growth* algorithm (FP-Growth), introduced by Han and Pei (2000), addresses computational limitations of traditional association rule (AR) mining by constructing a specialized data structure called an FP-tree that compresses datasets while preserving essential pattern information (*see* Fig. 2).

The algorithm operates in three steps: identifying frequent tourist behaviour (beach visits, accommodation choices, dining patterns) and ordering by frequency; constructing the FP-tree by mapping behavioural combinations; and mining patterns through divide-and-conquer strategy to reveal associations like '{Hotel, Beach}' or '{Nature Activities, Apartment Avoidance}'.

This enables identification of hierarchical behavioural patterns linking carbon offset willingness to actual consumption behaviours—relationships that traditional clustering methods cannot capture.

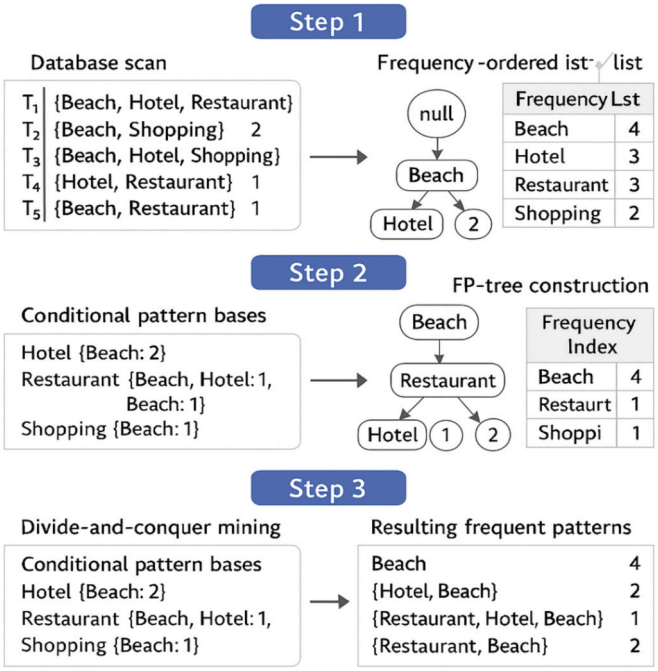

Fig. 2. FP-growth algorithm process: from tourist behaviour data to frequent pattern discovery.
Source: Own Elaboration.

3.2. Hierarchical association rules framework

Traditional tourist segmentation relies on single-level clustering that fails to capture the nested nature of environmental decision-making (Dolnicar et al., 2017). Tourists' stated environmental commitment often differs from actual behaviour due to budget constraints, cognitive biases, and practical circumstances.

Our Hierarchical Association Rules (HAR) framework addresses these limitations through three progressive levels (See Fig. 3.):

- Level 1: Foundational Environmental Segmentation establishes broad behavioural categories based on carbon offset willingness (0%, <10%, 10–20%, >20%). This captures the primary environmental commitment gradient while recognizing that identical percentages can mask different behavioural logics.
- Level 2: Intra-Segment Behavioural Differentiation applies FP-Growth within each Level 1 segment to identify distinct sub-patterns. This reveals how environmental attitudes interact with

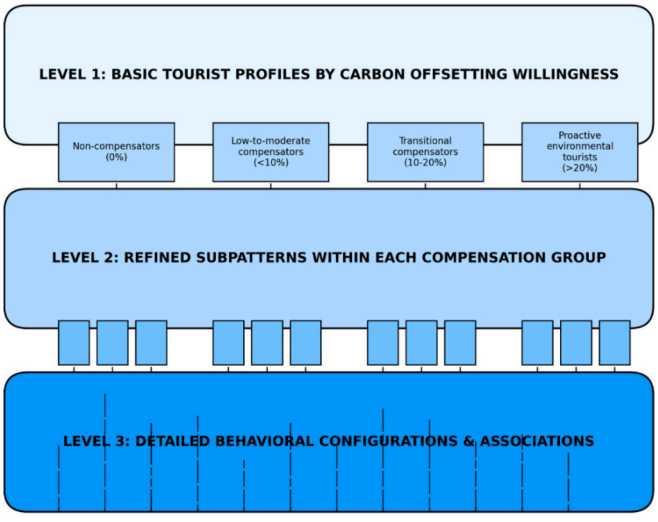

Fig. 3. Framework of the analysis.
Source: Own Elaboration.

practical travel behaviour's, uncovering the mediating role of socioeconomic factors and structural constraints.

- Level 3: Micro-Behavioural Configuration Analysis identifies specific rule-based behaviour combinations within Level 2 sub-patterns. This granular analysis distinguishes behavioural configurations like "aspirational eco-sympathizers" from "routine-oriented pragmatists" within the same compensation bracket.

The methodological innovation lies in how each hierarchical level builds upon and refines insights from the previous one, enabling us to move beyond traditional "attitudinal-behavioural gap" documentation. Rather than simply noting misalignment between environmental attitudes and behaviours, we identify the specific conditions under which environmental attitudes actually translate into sustainable actions.

This approach provides both theoretical insights into carbon offset willingness complexity and practical guidance for developing targeted interventions across diverse tourist segments.

4. Results

Fig. 4 maps the full behavioural architecture uncovered by the HAR framework, showing associations between carbon offset willingness and consumption patterns across all five compensation tiers. The five colour-coded anchor nodes — cyan (Not Compensate), green (Lower than 5%), orange (Lower than 10%), blue (Lower than 20%), and red (Greater than 20%) — connect to medium-sized nodes representing behavioural co-occurrence patterns and peripheral dots capturing lower-frequency associations. Line colour indicates segment membership; line thickness reflects association strength (confidence scores).

Two contrasting paths are particularly instructive. Tracing the red node (Greater than 20%), thick connecting lines lead toward "Sea–Natur" and "Sports–Natur" nodes, indicating high-confidence associations between proactive environmental tourists and nature-combined marine and sports activities.

Critically, this segment shows no connections toward all-inclusive or

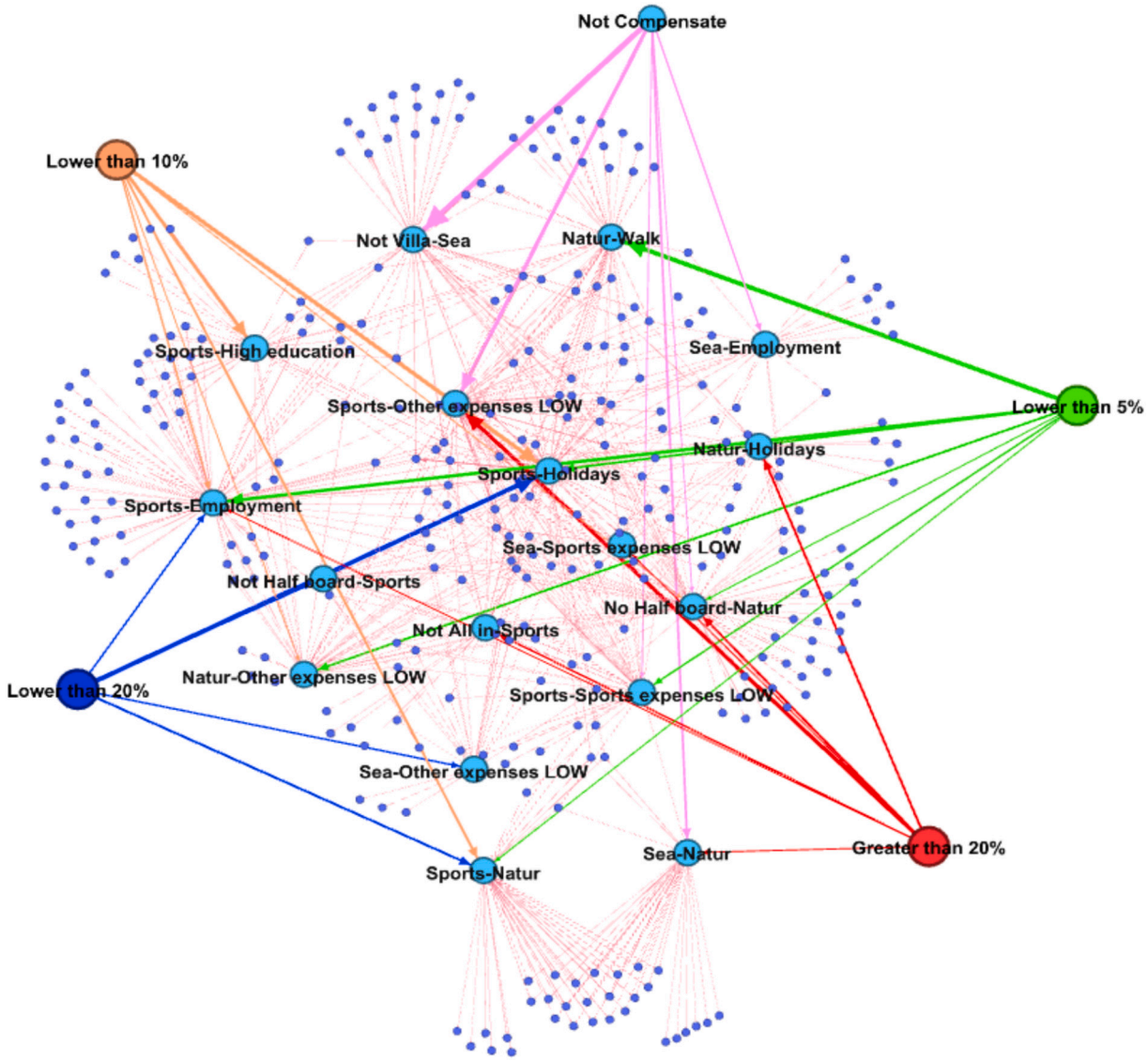

Fig. 4. Hierarchical association rules (HAR) for carbon offset willingness.
Note: The five large nodes represent the primary segments defined by carbon offset willingness, each assigned a unique colour: cyan (Not Compensate), green (Lower than 5%), orange (Lower than 10%), blue (Lower than 20%), and red (Greater than 20%). Medium-sized cyan nodes represent behavioural co-occurrence patterns identified by the FP-Growth algorithm, while small blue dots capture lower-frequency peripheral associations. Line colour indicates segment membership and line thickness reflects association strength, with thicker lines corresponding to higher confidence scores. Only rules meeting the minimum thresholds of 5% support and 60% confidence are displayed. *Source: Own elaboration.* (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

package-related nodes, reflecting a deliberate rejection of mass-tourism formats driven by ecological values. By contrast, the cyan node (Not Compensate) connects via thick pink lines toward "Natur–Walk" and "Sea–Employment" — a superficially similar activity set — yet its connections extend toward low-expenditure nodes, revealing that the underlying logic is cost-driven rather than ecologically motivated.

These two paths, visually proximate in the network but motivationally opposed, capture the central analytical argument of the study: surface-level behavioural similarity can conceal deep motivational heterogeneity that only becomes legible through hierarchical, multi-level pattern analysis. The three levels of analysis presented in the following subsections progressively unpack this heterogeneity.

4.1. Level 1: basic tourist profile

The Level 1 (bigger circles) analysis reveals four distinct profiles based on tourists' carbon offsetting willingness (Table 2). Cost-driven active tourists (0% offsetting) engage heavily in sports and marine activities while avoiding apartments and meal plans, reflecting a budget-focused mindset where recreational enjoyment takes precedence over environmental commitments. Balanced practical travellers (0–10% offsetting) combine similar activities with moderate sustainability interest, demonstrating pragmatic balance between environmental concern and financial constraints—typically employed individuals with higher education willing to contribute modestly without compromising leisure.

Selective eco-conscious tourists (10–20% offsetting) engage in nature and sport-based tourism while deliberately avoiding mass-tourism formats and inclusive meal plans. Predominantly educated and employed, they reflect selective sustainability approaches where authentic experiences align with moderate-to-high carbon offset willingness. Committed sustainability-oriented tourists (>20% offsetting) show the strongest environmental commitment, actively rejecting standard tourist offerings while maintaining diverse activity preferences that intentionally align with environmental values.

These profiles reveal a paradoxical pattern: sport and marine activities are prevalent among both the least environmentally committed (0%) and most committed (>20%) groups, suggesting that physical engagement is not inherently linked to environmental concern. Conversely, nature-based pursuits emerge consistently among moderate compensators (0–20%), indicating gradual alignment between environmental awareness and activity preferences.

This apparent contradiction—why cost-driven tourists share behavioural traits with sustainability-oriented tourists—alongside questions about how socioeconomic factors influence compensation behaviours, necessitates the deeper segmentation provided in Levels 2 and 3.

Table 2
Results Level 1.

Carbon offset willingness (%)	Tourist segment	Tourist behaviour	Interpretation
0	Cost-driven active	Engage in sports and marine activities, avoid apartments, minimize food expenses, reject meal plans.	Recreationally engaged tourists focused on low-cost, non-environmentally motivated activities.
(0−10]	Balanced practical	Combine sports, marine activities, and walking, avoid apartments.	Moderately environmentally aware tourists balancing activity-rich travel with affordability.
(10−20]	Selective eco-conscious	Prioritize nature and sports activities, avoid apartments and meal plans.	Higher education and employment support selective sustainable choices over traditional tourism.
>20	Committed sustainability-oriented	Seek nature and sport experiences, avoid apartments and packaged meals, vacation-motivated.	Diverse activity preferences with a strong environmental commitment.

Source: Own elaboration.

4.2. Level 2: refined sub-patterns

Level 2 (middle size cyan circles) analysis reveals 2–3 distinct sub-profiles within each carbon offsetting category, demonstrating how similar environmental willingness manifests through differentiated consumption patterns and motivations (Table 3).

Non-compensators (0%) split into structured package seekers who favour all-inclusive deals with low discretionary spending, and relaxed low-spenders who prefer independent, simple travel with basic services. Both reflect cost-sensitive approaches but through different consumption logics—structured versus independent planning.

Low-to-moderate compensators (<10%) encompass three profiles: passive leisure seekers who prioritize climate and beach activities with minimal spending; structured non-actives who combine package convenience with low expenditure (often unemployed); and climate-focused escapists who emphasize comfort over environmental considerations. All demonstrate symbolic offsetting willingness constrained by economic limitations and convenience preferences.

Transitional compensators (10–20%) show stronger attitude-behaviour alignment through: engaged experience-seekers who combine nature/marine activities with structured consumption; mid-range spenders who prefer dining out over self-catering; and climate-oriented planners who prioritize environmental attributes over price. These profiles reflect deliberate sustainability integration within controlled consumption frameworks.

Proactive environmental tourists (>20%) demonstrate highest autonomy and commitment via: independent affluent planners who avoid mass-tourism formats entirely; selective comfort seekers who maintain comfort while rejecting full packages; and nature-oriented conscientious tourists who combine environmental activities with financial restraint. All exhibits deliberated carbon offset willingness supported by planning autonomy and economic capacity.

These sub profiles resolve Level 1 paradoxes: while 0% and > 20% groups share activity preferences (marine sports, apartment avoidance), their underlying motivations differ fundamentally—budget-conscious recreation versus deliberate environmental selectivity. Similarly, low compensators' symbolic willingness reflects socioeconomic constraints rather than genuine environmental commitment, confirming that identical behaviours can stem from entirely different decision-making dynamics.

4.3. Level 3: detailed behaviour

Level 3 (the smallest circles) analysis examines intra-group variability within each offsetting category, revealing how tourists operationalize — or fail to operationalize — their environmental attitudes. The HAR analysis yields twelve behavioural configurations (three per bracket), listed in Table 4; the discussion below groups profiles sharing a common consumption logic and prioritizes those with the sharpest analytical leverage.

Non-compensators (0%) are internally less homogeneous than the label suggests. Package-dependent recreationists and budget bundlers share essentially the same structural foundation — bundled services, all-inclusive formats, low discretionary spending — and are functionally equivalent from a policy standpoint. The more revealing configuration is disengaged travellers, who remain disconnected from ecological and cultural aspects of travel despite comparatively high educational qualifications, ruling out a purely structural explanation of non-compensation: attitudinal passivity can persist even when

Table 3
Results Level 2.

Carbon offset willingness (%)	Tourist segment	Tourist Behaviour	Interpretation
0	Structured package seekers	Low discretionary spending on food and transport, all-inclusive packages, low environmental awareness.	Structured consumption with minimal environmental awareness.
	Relaxed low-spenders	Walking and beachgoing, low supermarket spending, basic meal service preferences.	Independent, simplicity-driven travel with passive environmental engagement.
	Passive leisure seekers	Beach and walking activities, low expenditure, preference for climate, travel in pairs.	Low-activity, low-cost tourism with symbolic willingness to offset.
(0–10]	Structured non-actives tourists	Use of package tours with meal plans, low expenditure, preference for convenience.	Convenience and cost-focused behaviour despite offsetting willingness.
	Climate-focused escapists	Focus on climate, disinterest in environmental aspects, low-cost leisure tourism.	Comfort-driven behaviour, sustainability secondary to climate preferences.
	Engaged experience-seekers	Nature and marine activity engagement, avoidance of intensive sports, hotel stays, meal plans.	Environmentally engaged tourists balancing activity with structured consumption.
(10–20]	Mid-range spenders	High restaurant spending, low supermarket use, preference for eating out.	Preference for dining out indicates semi-structured consumption behaviour.
	Climate-oriented planners	Climatic preference, moderate spending, avoidance of price-based decision making.	Deliberate travel planning aligned with environmental and comfort values.
	Independent affluent planners	Avoid hotels and packages, high education and income, not primarily vacation-motivated.	High-income, sustainability-conscious travellers avoiding mass-tourism formats.
>20	Selective comfort seekers	Meal-inclusive, selective accommodation choices, reject full-package deals.	Comfort without compromise, partial structuring of travel behaviour.
	Nature-oriented conscientious tourists	Engagement in nature and marine activities, low sports and restaurant spending.	Selective and environmentally guided activity participation with financial autonomy.

Source: Own elaboration.

informational preconditions for environmental engagement are met.

The low-to-moderate bracket (<10%) is where the attitude–behaviour gap becomes most visible. Habitual pragmatists and passive compliers both exhibit low destination interaction and minimal behavioural follow-through, though through routine and normative compliance, respectively. The most instructive configuration is aspirational sympathizers — tourists who express pro-sustainability attitudes and avoid package formats yet spend little and show no measurable consumption shift. Stated intent coexists with behavioural inertia, and the symbolic character of the commitment becomes apparent only when

Table 4
Results Level 3.

Carbon offset willingness (%)	Tourist segment	Tourist Behaviour	Interpretation
0	Package-dependent recreationists	Engage in passive leisure (beach, pool), prefer package tours with all-inclusive or structured meals, low spending in restaurants and sports.	Prioritize convenience and relaxation over sustainability or immersive travel; limited engagement with ecological criteria.
	Budget bundlers	Opt for bundled services (transport, food), low spending in food and sports, indifferent to environmental and price factors.	Structured consumption reflects budget-conscious behaviour, with minimal interest in sustainability or complexity.
	Disengaged travellers	Low concern for destination attributes (tranquillity, price, organization), limited activities, passive behaviour despite high education.	Travel as generic leisure experience, disengaged from both environmental criteria and cultural depth.
	Habitual pragmatists	Book familiar, mid-range options, avoid immersive or costly experiences, low spending in key categories.	Symbolic sustainability alignment driven by habit and simplicity, not deep ecological commitment.
(0–10]	Passive compliers	Minimal interaction with destination, favour ease and simplicity, low overall spending.	Willingness to offset stems from normative or social expectations rather than conscious ecological practice.
	Aspirational sympathizers	Positive attitudes toward sustainability, avoid packages, low expenditures despite indifference to price.	Support sustainability symbolically but without operational integration; limited behavioural follow-through.
	Climate-selective planners	Medium-level spending, climate as priority, avoid all-inclusive formats, mid-length stays, moderate education and income.	Demonstrate selective sustainable behaviour with flexible planning and low ecological impact formats.
(10–20]	Active eco-selectives	Nature and marine-based activities, personalized travel with structured autonomy, moderate awareness.	Reject mass-tourism in favour of ecologically compatible choices; balance between comfort and values.
	Pragmatic greeners	Avoid extreme low-cost or high-impact behaviours, rest-motivated, selective yet not overtly ecological.	Pragmatic alignment with sustainability discourses; intermediate position between symbolic and strategic action.
>20	Autonomous planners	Avoid all-inclusive and hotels, emphasize planning and destination	Autonomous travellers with strong environmental

(*continued on next page*)

Table 4 (*continued*)

Carbon offset willingness (%)	Tourist segment	Tourist Behaviour	Interpretation
		quality over convenience.	preferences and efficient consumption patterns.
	Intentional minimalists	Low expenditure by choice, avoid standard leisure formats, high environmental awareness.	Deliberate simplicity driven by ecological values rather than cost constraints.
	Committed environmentalists	Highly educated, structured and impact-aware consumption, travel for development not relaxation.	Consistently integrate sustainability into motivations, attitudes, and practices.

Source: Own elaboration.

consumption data are examined alongside attitudinal indicators (Juvan & Dolnicar, 2014).

A qualitative shift is observable in the transitional bracket (10–20%). Climate-selective planners filter destinations on environmental and comfort attributes; active eco-selectives construct personalized itineraries around nature and marine activities. What distinguishes both from superficially similar lower-bracket profiles is that environmental criteria function as active selection parameters rather than retrospective justifications. Pragmatic greeners avoid conspicuously high-impact behaviours without explicit ecological framing, suggesting a pragmatic rather than principled orientation. Together, these configurations confirm the 10–20% range as a genuine transitional zone where environmental values have entered the decision calculus, though with varying degrees of intentionality.

Proactive environmental tourists (>20%) display the most consistent value–behaviour alignment. Autonomous planners and intentional minimalists both exercise high planning independence, differing only in whether selectivity prioritizes destination quality or deliberate frugality. The analytically decisive configuration is committed environmentalists, who integrate sustainability across motivations, attitudes, and practices, and travel for personal development rather than passive relaxation. This profile ultimately resolves the paradox identified at Level 1: the highest-offsetting tourists share surface-level activity preferences with non-compensators, but the underlying decisional logic — ecological intentionality versus cost minimization — is fundamentally different.

Two broader patterns deserve explicit mention. First, the same observable behaviour can encode opposite motivational logics depending on the compensation bracket, cautioning against interpreting activity participation as a reliable proxy for environmental commitment. Second, the transition from symbolic to committed offsetting is not linear: the 10–20% bracket operates as a threshold beyond which environmental criteria begin to actively structure consumption choices. Both patterns carry direct consequences for intervention design.

5. Discussion and policy implications

This study employed a multi-layered analytical framework to investigate carbon offsetting willingness heterogeneity and underlying behavioural configurations. By structuring the analysis across three progressive levels, we captured both environmental commitment gradients and the detailed consumption patterns through which sustainability orientations are enacted—or merely declared. Level 1 established four broad segments corresponding to stages of environmental behaviour ranging from awareness to behavioural integration (Kollmuss & Agyeman, 2002). Level 2 revealed within-group heterogeneity consistent with the Theory of Planned Behaviour (Ajzen, 1991), demonstrating that identical offsetting willingness manifests through different behavioural modes depending on socioeconomic constraints and consumption preferences. Level 3 extracted association rules that expose latent behavioural configurations, providing segmentation grounded in co-occurrence patterns rather than a priori assumptions (Dolnicar et al., 2017).

Before extending this discussion, the conceptual status of the core variable warrants clarification. Carbon offset willingness, as operationalised in the EGT survey, captures a stated disposition to allocate a proportion of destination expenditure toward emissions compensation — neither a behavioural outcome nor a unitary psychological construct. We interpret it as a graded attitudinal indicator of pro-environmental engagement whose empirical validity is strengthened when intersected with observed consumption patterns through the HAR framework. This intersection partially attenuates the well-documented limitations of self-reported environmental intent (Juvan & Dolnicar, 2014), though willingness remains a stated intention rather than a verified transaction. Accordingly, the policy instruments advanced below are calibrated to the motivational and behavioural structures associated with each tier rather than predicated on the assumption that declared percentages translate into actual financial contributions.

The hierarchical findings speak to three ongoing conceptual debates in sustainable tourism behaviour research. The first concerns the nature of the attitude–behaviour gap. Existing literature has largely treated this as a unitary phenomenon — a measurable distance between what tourists declare and what they do (Juvan & Dolnicar, 2014). Our Level 3 analysis complicates this reading: within the same willingness bracket, configurations such as aspirational sympathizers and passive compliers exhibit comparable behavioural outcomes through fundamentally different mechanisms — unfulfilled ecological conviction in one case, normative compliance without underlying commitment in the other. The gap is not a single space but a heterogeneous terrain traversed by distinct motivational pathways, and interventions that ignore this internal structure risk targeting the wrong mechanism.

The second implication concerns the assumed linearity of pro-environmental progression. Influential frameworks such as Kollmuss and Agyeman's (2002) barrier model and stage-based adaptations of the Theory of Planned Behaviour (Ajzen, 1991) implicitly treat the movement from environmental awareness to behavioural integration as a gradual, incremental process. Our results suggest otherwise. The 10–20% bracket does not represent a midpoint on a continuous scale but a qualitative threshold beyond which environmental criteria shift from accompanying consumption decisions to actively structuring them. This threshold-dependent pattern calls for models that accommodate discontinuities in the relationship between environmental attitudes and travel behaviour rather than assuming smooth progression.

Third, the hierarchical structure of the analysis contributes to the segmentation debate in sustainable tourism (Dolnicar et al., 2017). Had the analysis been confined to Levels 1 and 2, it would have produced a misleading equivalence between non-compensators and proactive environmental tourists, both of whom engage in marine sports and avoid apartment accommodation. Only Level 3 reveals that these shared behaviours encode opposing decisional logics—cost minimization versus ecological intentionality. This demonstrates that meaningful behavioural segmentation in sustainability contexts requires analytical depth beyond single-tier classification, as surface-level behavioural similarity can conceal the motivational heterogeneity that ultimately determines responsiveness to policy instruments.

These conceptual advances find practical expression when projected beyond the Canary Islands. The behavioural architecture and hierarchical segmentation deployed here are relevant to tourism-intensive destinations that share structural features—air-access dependence, concentrated demand in coastal or insular corridors, widespread packaged products, and environmentally sensitive ecosystems.

While the prevalence of segments will vary by market, the fourfold

typology (non-compensators, low-to-moderate compensators, transitional compensators, and proactive environmental tourists) offers a portable diagnostic that links willingness to offset with concrete consumption choices. Rather than prescribing a single implementation pathway, this diagnostic enables destinations to align choice architectures, incentive structures, and recognition schemes with the profiles they aim to activate, and to evaluate progress using routine performance indicators suited to local capacities. Table 5 translates this diagnostic into group-specific policy objectives and instruments, drawing directly on the behavioural configurations identified in Level 3.

Non-compensating tourists (0%) align with what the behavioural literature defines as low-agency consumers, whose decisions are shaped more by convenience and habit than by reflective sustainability considerations (Thøgersen, 2005). Full behavioural transformation is an unrealistic objective for this segment. Interventions should instead reconfigure the consumption environment so that sustainable outcomes occur without requiring active engagement. The most direct mechanism is the integration of carbon offsetting into tourism packages by default, shifting the decision architecture from opt-in to opt-out.

Experimental evidence suggests that default-based mechanisms can significantly increase participation in offsetting schemes among otherwise disengaged consumers (Ebeling & Lotz, 2015). Complementary supply-side measures—such as the incorporation of low-carbon components (sustainable meals, electric transfers, carbon credits) as standard inclusions in all-inclusive and bundled offerings—embed sustainability into the service structure rather than delegating it to individual choice. For this group, the operative principle is that the path of least resistance should also be the path of lowest environmental impact (Dolnicar et al., 2015).

Table 5
Policy objectives and suggested instruments by carbon offset willingness groups derived from Level 3 analysis.

Tourist Group	Diagnosis	Policy Objective	Suggested Instruments
Non-compensators (0%)	Low agency, routine-driven behaviour; limited environmental salience; reliance on structured, mass-tourism formats.	Activate minimal pro-environmental engagement through default settings and normative cues.	Default offset integration; value-framed messages during booking; symbolic eco-rewards; redesign of all-inclusive offers.
Low-to-moderate compensators (<10%)	Symbolic environmental concern; constrained by economic and cognitive barriers; passive and routinized behaviours.	Facilitate transition from symbolic to incremental behavioural commitment with low-friction interventions.	Opt-out offsetting in online platforms; eco-certification of mid-range services; partnerships with tour operators; behavioural monitoring.
Transitional compensators (10–20%)	Emergent coherence between environmental attitudes and actions; selective rejection of mass-tourism formats.	Consolidate emergent sustainable behaviours into stable, routine travel practices.	Carbon calculators; reward schemes for low-carbon choices; affective default framing; transparent low-impact travel options.
High compensators (>20%)	Deliberate alignment of behaviour with sustainability values; high planning autonomy; detachment from conventional tourism patterns.	Amplify and mainstream existing sustainable behaviours; recognize and engage tourists as co-producers of sustainability.	Access to verified offset projects; tax incentives; traveller recognition programs; participatory governance mechanisms.

Source: Own elaboration.

Low-to-moderate compensators (<10%) express positive environmental attitudes that remain largely declarative. The policy challenge is therefore not activation but conversion — translating latent intent into incremental behavioural shifts. Eco-certification schemes with standardized labels for mid-range accommodations can reduce the cognitive effort needed to identify sustainable options, while public-private partnerships with tour operators and booking platforms help shape the information environment in which decisions are made. Communication should favour relatable, normatively anchored appeals over technical or moralistic framing, reinforcing that modest contributions are both meaningful and socially endorsed.

Transitional compensators (10–20%) have moved beyond symbolic engagement; the policy objective shifts from facilitating participation to consolidating emerging sustainable routines. Carbon calculators quantifying the environmental impact of specific choices can reinforce decisional intentionality, while cumulative reward schemes strengthen habit formation. Hybrid opt-in mechanisms with affective framing have demonstrated efficacy in nudging offsetting participation among moderately engaged tourists (Araña & León, 2013) and should leverage the planning autonomy and moderate spending capacity that distinguish this segment.

Proactive environmental tourists (>20%) require a qualitatively different policy logic — not activation or consolidation, but amplification. Verified, high-impact offsetting schemes with transparent local co-benefits address documented frustration over the lack of credible compensation channels (Gössling et al., 2007). Fiscal incentives for sustainability-certified expenditure can mainstream these practices at scale. Beyond individual instruments, this segment holds distinctive potential for participatory governance — co-designing sustainability criteria, peer-reviewing offsetting mechanisms, or serving as normative catalysts for broader demand-side shifts.

Across all tiers, an equitable transition requires acknowledging that tourists differ not only in willingness but also in capacity and structural constraints. Targeted strategies must expand the conditions under which pro-environmental behaviour becomes feasible for all groups, including those with limited economic flexibility (Rastegar, 2022).

6. Conclusion

This study demonstrates the analytical potential of hierarchical pattern mining for advancing the understanding of tourist behaviour and environmental commitment. By applying Hierarchical Association Rules (HAR) within a three-tiered framework, we systematically examined the relationship between tourists' willingness to offset their carbon footprint and their actual consumption patterns. This approach allowed us to move beyond conventional segmentation, revealing internal heterogeneity within willingness groups and exposing behavioural patterns that aggregate analyses routinely overlook.

The study advances sustainable tourism research on two fronts. Theoretically, the findings challenge prevailing conceptualisations of the attitude–behaviour gap as a uniform phenomenon, revealing it instead as a heterogeneous terrain where distinct motivational pathways—from normative compliance to unfulfilled ecological conviction—produce superficially similar outcomes. The results further demonstrate that pro-environmental progression is not incremental but threshold-dependent, with intermediate compensation brackets marking a qualitative shift in how environmental criteria structure consumption decisions.

These insights contribute to behavioural stratification theory and to models of sustainable tourism decision-making by introducing discontinuity and motivational multiplicity as organising principles for tourist segmentation. Methodologically, the study represents the first application of the FP-Growth algorithm to behavioural segmentation in sustainable tourism, offering a hierarchical alternative to conventional

approaches—clustering, regression-based segmentation, and latent class analysis—that typically operate at a single analytical tier and cannot capture the nested, multi-level co-occurrence structures through which offsetting willingness relates to concrete consumption choices.

The study identifies four tourist groups based on willingness to offset carbon emissions, each exhibiting internal behavioural diversity. Non-compensators display routinized patterns shaped by package tourism and low environmental salience. Low-to-moderate compensators show aspirational sustainability engagement that remains largely symbolic. Transitional compensators exhibit partial but growing coherence between pro-environmental attitudes and consumption choices. Proactive environmental tourists demonstrate deliberate value–behaviour alignment, favouring planning autonomy and low-impact practices. These findings underscore the relevance of segmenting tourists not only by attitudinal indicators but also by the consistency of their behavioural patterns, revealing differentiated pathways toward sustainable consumption.

These configurations call for targeted interventions tailored to each group's barriers and capacities. For low-engagement tourists, the priority is embedding sustainability by default through low-friction mechanisms such as opt-out offsetting or reconfigured package deals. Aspirational segments require reduced activation costs and simplify eco-options to translate intention into practice. Transitional tourists benefit from supportive infrastructures reinforcing emerging sustainable routines, while proactive travellers respond to fiscal incentives, participatory governance, and recognition schemes. This tiered approach aligns with recent calls for behaviourally informed tourism policies (Dolnicar & Demeter, 2024), positioning destination managers as key agents in facilitating effective sustainability transitions (Gössling & Higham, 2021).

While our study provides valuable insights into tourists' environmental behaviour, several limitations warrant acknowledgment. First, carbon offset willingness is interpreted throughout this study as a graded attitudinal indicator rather than a verified behavioural outcome, and reliance on self-reported survey data may introduce recall and social desirability biases. Second, the cross-sectional "snapshot" design does not capture how attitudes and practices evolve over time. Third, although our empirical setting is the Canary Islands, we expect the behavioural architecture and fourfold typology to be portable primarily to tourism-intensive destinations that share key structural features—air-dependent access, concentrated coastal/insular demand, widespread packaged products, and fragile ecosystems. Caution is therefore needed when extrapolating to contexts with different dynamics (e.g., urban, rural, cultural), where mobility patterns, product mixes, and governance structures differ materially.

Future research could address these challenges through several promising avenues. Longitudinal studies tracking the same tourists over time would reveal behavioural evolution and help control for individual differences we cannot observe. Combining survey responses with real-world data—actual booking records, spending patterns, or mobile tracking—would overcome the reliability issues inherent in self-reported behaviour. Expanding beyond island destinations to include urban, rural, and other tourism contexts would test whether our hierarchical framework holds across different settings. Finally, integrating advanced machine learning techniques could enhance our ability to predict tourist behaviour and support dynamic policy applications. These methodological advances would strengthen both the explanatory power and practical applicability of hierarchical pattern analysis in understanding tourist environmental behaviour.

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CRediT authorship contribution statement

Aythami Santana-Padrón: Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Eugenio Diaz-Farina:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Investigation, Formal analysis, Data curation, Conceptualization. **Andrea Rodríguez:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this paper, the author(s) used *Quillbot* to search for synonyms, find proposed alternative wording for some sentences and identify possible errors caused by dyslexia disorders in one of the authors. After using this tool/service, the authors reviewed and edited the content as necessary and take full responsibility for any errors. Additionally, as the authors are not native English speakers, *grammarly* has been used to correct grammatical errors and improve the quality of the writing.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

Appendix A. Supplementary data

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