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Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Perceptions of change in the environment caused by the COVID-19 pandemic: Implications for environmental policy

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ABSTRACT

COVID-19 lockdown measures have impacted the environment with both positive and negative effects. However, how human populations have perceived such changes in the natural environment and how they may have changed their daily habits have not been yet thoroughly evaluated. The objectives of this work were to investigate (1) the social perception of the environmental changes produced by the COVID-19 pandemic lockdown and the derived change in habits in relation to i) waste management, energy saving, and sustainable consumption, ii)

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Social behaviours
Natural environment

mobility, iii) social inequalities, iv) generation of noise, v) utilization of natural spaces, and, vi) human population perception towards the future, and (2) the associations of these potential new habits with various sociodemographic variables. First, a SWOT analysis identified strengths (S), weaknesses (W), opportunities (O), and threats (T) generated by the pandemic lockdown measures. Second, a survey based on the aspects of the SWOT was administered among 2370 adults from 37 countries during the period from February to September 2021. We found that the short-term positive impacts on the natural environment were generally well recognized. In contrast, longer-term negative effects arise, but they were often not reported by the survey participants, such as greater production of plastic waste derived from health safety measures, and the increase in e-commerce use, which can displace small storefront businesses. We were able to capture a mismatch between perceptions and the reported data related to visits to natural areas, and generation of waste. We found that age and country of residence were major contributors in shaping the survey participants answers, which highlights the importance of government management strategies to address current and future environmental problems. Enhanced positive perceptions of the environment and ecosystems, combined with the understanding that livelihood sustainability, needs to be prioritized and would reinforce environmental protection policies to create greener cities. Moreover, new sustainable jobs in combination with more sustainable human habits represent an opportunity to reinforce environmental policy.

1. Introduction

The rapid human population growth and the corresponding increased use of resources are causing huge challenges to ensure healthy human and ecological systems. In response to these grand challenges, since the early 2000s, numerous organizations and governmental institutions worldwide have conceived and promoted sustainable ecological transitions based on models of a circular economy with initiatives to support sustainable development. Examples of such initiatives are the "2005 World Summit on Social Development" based on sustainability development (UN General Assembly, 2005) and, likewise, the Sustainable Development Goals (SDGs) program, initiated in 2015 by the United Nations (https://www.eea.europa.eu/policy-documents/eu-biodiversity-strategy-for-2030-1). However, the COVID-19 pandemic, an unprecedented event in modern times, has affected the development of these sustainability programs (Zhang et al., 2020; Wang and Su, 2020). The pandemic has led to the prioritization of public health measures (lockdowns, vaccination programs) and economic recovery over the continued development and implementation of sustainability agendas (You et al., 2020; Cheval et al., 2020).

The COVID-19 restrictions, which governments imposed to limit social interactions and to prevent transmission of the disease through human physical proximity, have produced environmental effects that differ in duration (into short-term effects, lasting months, to long-term effects, lasting years), and direction (positive or negative effects) Helm, 2020; Institute for Global Environmental Strategies (IGES), 2020; Cheval et al., 2020; Sharifi and Khavarian-Garmsir, 2020). While many long-term effects remain to be clarified, lockdowns and reduced activity have produced negative short-term effects on employment rates (Galanti et al., 2021), tourism, commerce, and industry, with devastating effects on the global economy (Bashir et al., 2020; Cheval et al., 2020; Nilashi et al., 2020). Previous studies have highlighted the massive shift towards remote work (in particular during the initial peak of the pandemic) and hybrid forms of work (during later stages of the pandemic), which were associated with an overall reduction in the number of commuting trips, in particular during peak time, as well as modifications in the use of various modes of transport (Matson et al., 2022). Among other related changes in activities and travel, a substantial increase in the use of online shopping was observed (Young et al., 2022) while the use of active modes of transport (including walking and bicycling) experienced some temporary renaissance and increased popularity, even if many of the latter changes were only temporary and rather short-lived as the pandemic evolved (McElroy et al., 2022). From a psychosocial perspective, the pandemic has increased anxiety and stress levels, decreased well-being (Franceschini et al., 2020; Shailaja et al., 2020) and increased social disparities causing vulnerable groups to be disproportionately impacted (Sharifi, 2022). Positive short-term environmental impacts initially emerged, such as a noticeable improvement in environmental conditions, mostly linked to reduced road traffic and consequent decreases in noise and air pollution. In particular, reduced emissions from the industry sector and urban traffic led to notable reductions in NO_2, SO_2, and $PM_{2.5}$ and PM_{10} emissions (Nilashi et al., 2019; Bates et al., 2020; Mousazadeh et al., 2021; Prakash et al., 2021; Querol et al., 2021).

Moreover, reduced human activity has led to water quality improvement (Lokhandwala and Gautam, 2020; Yunus et al., 2020) and increased wildlife activity in urban and peri-urban environments (Paital, 2020; Bates et al., 2021a). Research has confirmed these positive impacts of the COVID-19 pandemic, particularly during periods when lockdown measures were widely enforced (Zambrano-Monserrate et al., 2020; Cheval et al., 2020). Awuchi et al. (2020) called this positive impact "Endorsement of Green Recovery", which is being widely recognized as having a positive influence on human health and well-being via the use of green spaces (Lal et al., 2020; Lutu et al., 2020; Malliet et al., 2020). However, the global COVID-19 pandemic has also generated new human habits and behaviours that may drive societal change, and consequently, new anthropogenic impacts with positive and negative outcomes (e.g., Klemeš et al., 2020; Rupani et al., 2020; Paital et al., 2020; Wang et al., 2022). The aforementioned literature has deeply studied these impacts, but the respondent's perception of these changes remains unclear and not extensively studied. Recent literature search (i.e. Web of Science; November 2022) revealed that the topic of perception has not been well studied (Sharifi, 2022). For instance, Büssing et al. (2020a, 2020b) studied the perceived changes of certain attitudes and Ruiu et al. (2022) studied how the COVID-19 pandemic has impacted the perception of climate change in the UK though these studies generally remain specific to certain contexts and geographical regions. The public awareness about these impacts offers an opportunity to develop effective future policies to protect the environment (Mousazadeh et al., 2021; Soni and Mistur, 2022) and develop better urban planning (Sharifi, 2022).

Previous studies in India and China have analysed the impacts of restriction measures and COVID-19 pandemic management using a SWOT framework (Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T)) (Thakur, 2021; Zhou et al., 2021). However, this type of analysis has not been applied in other parts of the world, and studies on new habits due to the COVID-19 pandemic and respondent perception are scanty at a global scale.

This study explores the public awareness about the effects of the COVID-19 pandemic on the environment and those novel human habits that arose during the pandemic, in an international context, and across a variety of cultures, sociodemographic conditions, and geographical locations. Our goals are to illuminate emerging patterns and differences in human activities and behaviours, and to suggest measures required for mitigating impacts of restrictive public health measures in the future by integrating urban governance strategies (Van der Hel, 2018; Sharifi and

Khavarian-Garmsir, 2020). We focus on associations between these potential new habits and a variety of socio-demographic variables, including country of residence (in relation to the COVID-19 management measures), cultural and socioeconomic regimes, and social status. To achieve these objectives, we first look critically at the pandemic through internal strengths, weaknesses, external opportunities, and threats (in the SWOT framework). Afterwards, we analyse data collected with an international survey that administered among a large group of respondents across 37 countries eliciting their perceptions on i) waste management, energy saving and sustainable consumption, ii) travel behaviour and mobility, iii) gender and social inequalities, iv) perceptions about noise generation, v) perception about the environment and natural spaces, and vi) human perception towards the future and the pandemic. Additionally, we analysed attitudes towards travel by plane, purchasing behaviours, and visits to natural areas to contrast behaviours before and during the pandemic.

2. Material and methods

2.1. SWOT analysis and development of the survey

The research strategy was based on a mixed-method approach. We first conducted a SWOT analysis (Teddlie and Tashakkori, 2010; Appendix A) to detect societal and physical shifts as a result of the COVID-19 pandemic. "*Strengths*" were considered as intrinsic or direct improvements in environmental features, derived from the pandemic. "*Weaknesses*" were attributes that can undermine the achievement of the "*Strengths*". Conversely, "*Opportunities*" included changes that could potentially, if left unchecked, contribute to environmental conservation and maintenance of natural services. "*Threats*" were features that might prevent the detection of opportunities. From the results of the SWOT analysis, we identified six groups of behavioural variables and designed an online survey with specific questions for each group designed to assess people's new lifestyle habits (behavioural variables) in the context of socio-demographic variables, including age, country, gender, parenthood, areas of knowledge, and employment situation.

The survey contained 34 questions with different structures including multiple response questions, open-ended text fields, qualitative (yes/no questions), and quantitative, several types of quantitative questions measured in form of frequency scales or levels of agreement with certain statements, among others (content of the survey is reported in Appendix B). The survey was administered online among participants who were over 18 years old from 37 countries. The respondents were recruited via a convenience sampling approach, through invitations sent out among professional organizations, academic networks, various listservs, and social media. Our aim was to include, at least, the European countries that had been most affected by the pandemic, according to the European Centre for Disease Prevention and Control (2021) and Johns Hopkins University (2021): France, Germany, Greece, Ireland, Italy, Portugal, Slovakia, and Spain. We complemented these target countries with India and Mexico, which are densely populated countries in the Northern Hemisphere and which, consequently, were highly affected by the COVID-19 pandemic (https://www.worldometers.info/coronavirus/). In total, we received completed surveys from 37 countries (Fig. 1).

The administration of the survey started with a 34-question online pilot survey in Spain (N = 300 respondents). The pilot survey, in Spanish, was modified, as needed, to improve comprehension and translated into four languages (English, Portuguese, Italian and French). Respondents completed the online survey after the first wave of the COVID-19 pandemic, from February to September 2021a. As a result of the recruitment process, a total of 2370 valid entries were received, including the first 300 from Spain that were used to refine our methodology.

2.2. Statistical analysis

We analysed the diversity of the survey participants in the aforementioned socio-demographic variables. To reduce bias, we included in the analyses data from those countries returning an adequate sample size for further processing (whereby responses comprised >0.55% of the total number of responses).

Pearson's χ^2 tests were used to detect whether the behavioural variables were associated with the demographic variables. Yates's correction was applied when tables were 2*2 or less (Camilli and Hopkins, 1978). The *p*-values were corrected according to Benajmini and Hochberg approach to control the Type I error rate by means of "stat" base package implemented in R software (Benjamini and Hochberg, 1995; R Core Team, 2021).

Three pairs of questions compared the behaviour of the respondents based on three main aspects before and during the pandemic (Q15–16 for travels by plane, Q22–23 for purchasing behaviour, and Q25–26 for the number of visits to natural areas). In the first step, the answers were categorized on a numeric scale, being 0 in the absence of that behaviour (i.e., "never" answer), 1 in the lowest frequency of that behaviour, and 3 or 4 in the highest frequency depending on the number of possible answers to that question. By doing so, the answers were ranked in a scale that allow determining how many steps the respondents changed in their habits during the pandemic. Then, paired Mann-Whitney-Wilcoxon tests were performed to compare all the responses concerning before and

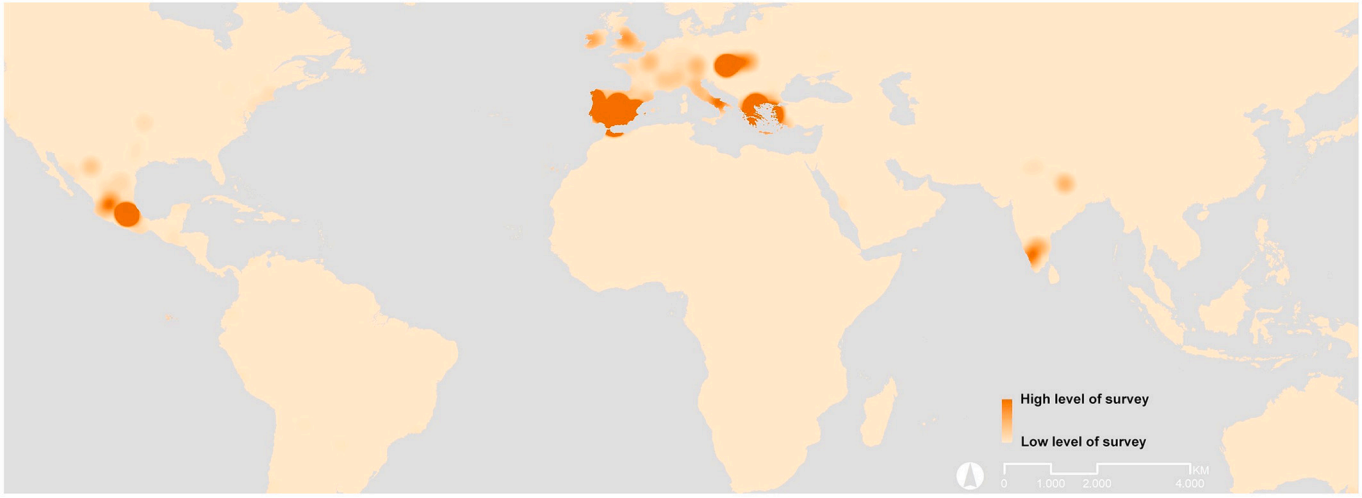

Fig. 1. Survey density map. Scale 1:140,000,000.

during the pandemic as a whole. This non-parametric test was chosen due to non-normal distributions (Kolmogorov-Smirnoff test with Lilliefors correction; $\alpha = 0.05$). In a second step, the intensity of these changes was calculated for each participant by subtracting the value during the pandemic from the value before it. Additionally, the intensity of the changes was also associated with demographic variables by creating three-dimensional figures (the third dimension using colour intensities) where the overall index ranged from −4 (weakest) to 4 (strongest). This intensity was associated with the socio-demographic variables in pairs to compare all the combinations of variables. Only combinations of socio-demographic factors with at least 20 responses were considered to avoid a bottleneck effect.

All statistical analyses were performed using R software, version 4.1.0.

3. Results

3.1. Socio-demographic information of the participants

Responses were homogeneously distributed in terms of age and knowledge areas (Fig. 2A and 2E). The countries with the most respondents were Spain, Greece, Portugal, and Mexico, followed by Slovakia, Italy, France, the UK, Germany, and Ireland (Fig. 2B). Most participants did not have children (66%; Fig. 2C), with a larger proportion of women participating in the survey than other genders (Fig. 2D), a feature that is common to many other surveys administered with similar approaches. Of all participants, over 90% declared they were employed, students, or a combination of both (Fig. 2F).

3.2. Knowledge about the behaviours relevant to the environment

Independently of the behavioural groups of questions, the survey results (Supplementary material 1: Figs. S1 to Fig. S26) were classified into the following SWOT categories:

3.2.1. Weaknesses

The increase in the consumption of hospital resources, the generation of clinical waste (e.g., test kits, masks), and the waste derived from packaging emerged as important concerns by respondents. Half of the respondents reported making use of at least one COVID-19 test (Q8: Fig. S1) since the beginning of the pandemic to the moment when the survey was done (50% did “between 2-5 tests” and “more than 5 tests”). Moreover, the use of disposable masks increased (Q9: Fig. S2); while 26% of the surveyed people showed that they used washable masks, >19% indicated using >20 disposable masks per month from the beginning of the pandemic. However, 36% of all participants indicated that they used the same quantity of disposable household products (plastic cutlery, disposable gloves) as before the pandemic, while 21%

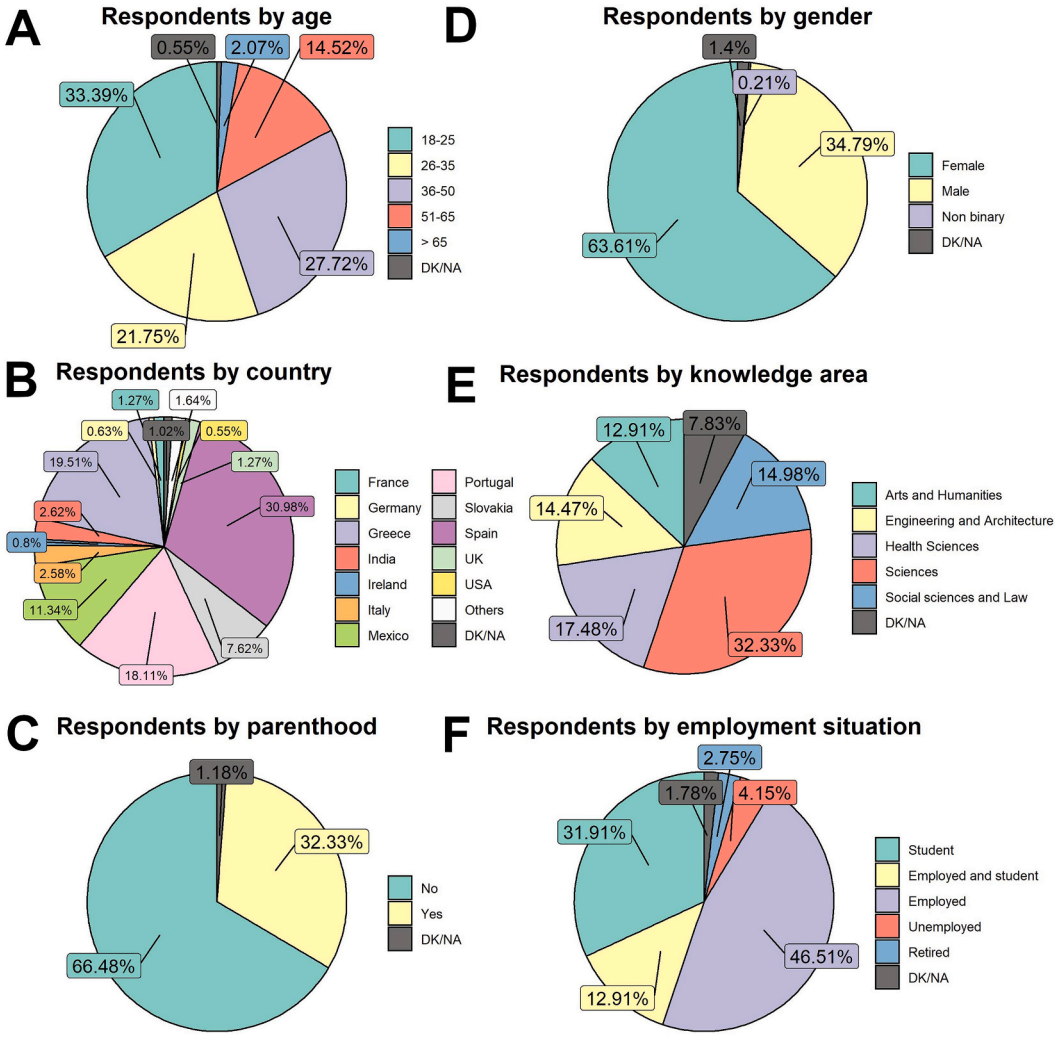

Fig. 2. Percentage of responses grouped by socio-demographic variables: A. Age. B. Country. C. Parenthood. D. Gender. E. Knowledge area. F. Employment situation. DK/NA: I don't know / I don't want to answer/Not applicable. $N = 2370$.

used more than prior to the pandemic onset, only 8% used less, 34% did not use these types of products, and 0.5% chose the Did not know / Not applicable category (Q10: Fig. S3). Respondents reported in response to questions on purchasing behaviour (sustainable consumption, Q22–23), an increase in online shopping since the beginning of the pandemic (i.e. an increase in e-shopping), where the frequency of choosing the categories "1 to 3 times a month" and "more than 3 times a month" increased by >10 percentage points (Fig. S14–15). Although the pandemic could provide an opportunity to promote technology for remote work, for those participants who continued physically commuting physically commute to their workplace (Q14: Fig. S7), the majority (91%) indicated that they did not change their transport model with private vehicle use being prevalent. Additionally, more that 72% of respondents thought that the reduction of tourism by the lockdown restrictions had harmed the cities economically (Q28: Fig. S20).

3.2.2. Threats

We grouped threats into inequalities that were based on gender and social groups. Forty-eight percent of respondents believed that all subsections of the society have been equally affected by the pandemic (Q17: Fig. S10); however, 25% indicated that older people were most affected. Respondents strongly indicated that the urban population was most affected by the pandemic (78%; Q19: Fig. S12). Respondents indicated that the pandemic worsened gender inequality in the workplace, with 35% indicating no effect, while 28% and 25% indicated they "have perceived inequalities" or they "were with doubt", respectively (Q18: Fig. S11).

3.2.3. Strengths

Strengths emerged in waste management, energy-saving, and sustainable consumption. Respondents noticed reduced food-related waste after decreasing purchased quantities and improving choices (Question-Q24: fig. S16). Only 18% of surveyed respondents indicated buying a greater quantity of products during the pandemic. Additionally, commitment to sustainable mobility and transport options emerged during the pandemic as work shifted to remote platforms and fewer respondents needed to physically commute to their workplace. Although around one-third of respondents (32%; Q13; Fig.S6) worked in person (physically) also during the pandemic, a similar percentage (29%) switched to remote work. The remaining (29%) used a mixed (hybrid) working model. Perceptions of noise generation (Q21; Fig. S13) were also impacted by lockdown measures. Almost half (47%) noticed noise reduction due to the pandemic, whereas 40% noticed no changes in environmental noise levels. Respondents' relationships with the environment and natural areas improved. A large majority of the respondents (95%; Q29: Fig. S21) attributed high value to natural spaces during the pandemic.

3.2.4. Opportunities

A high percentage (80%) indicated that "green jobs" (positions in agriculture, manufacturing, administrative, and service activities aimed at protecting and promoting the environment) could help solve this pandemic rather than jobs with poorer job security (Q30: Fig. S22), and 90% agreed that 2021 presented a good opportunity for their countries to shift to more sustainable policies (Q32: Fig. S24). However, only 45% of the respondents thought that the environmental situation in their countries would improve in 2021a (Q31; Fig. S23). Finally, 77% strongly considered that the new habits created during the pandemic would last over time (Q34: Fig. S26).

3.3. Effects of socio-demographic aspects on the behavioural variables

Most of the behavioural variables varied significantly in response to the socio-demographic variables (Fig. 3). Effects of socio-demographic

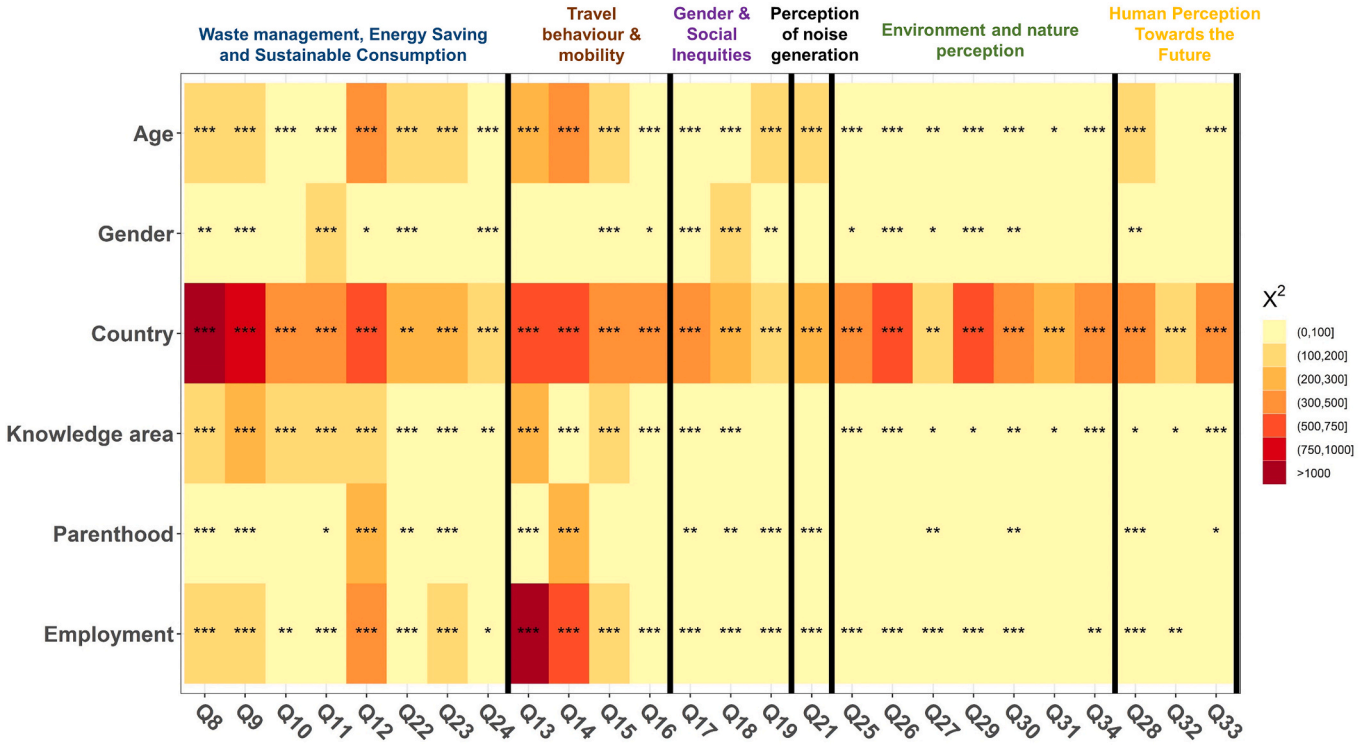

Fig. 3. Pearson's χ^2 tests statistic values (colours) and significance levels obtained by comparing the responses to each question of the survey. $N = 2370$, significance levels are: $p \leq 0.05$ (*), $p \leq 0.01$ (**), $p \leq 0.001$ (***). Yates correction was applied when needed (in tables of 2*2 dimensions) and p-values were corrected by means of Benjamini and Hochberg (1995) approach. Colour intensity (red) highlights higher χ^2 statistic values representing greater differences between the expected and observed distribution of responses. See Appendix B for the question content. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

aspects by country, gender, age, employment situation, and parenthood on behaviours are plotted in Supplementary material 2.

Behaviours and life habits concerning waste management, energy saving, and sustainable consumption (Q8 to Q12 and Q22 to Q24) varied significantly depending on various socio-demographic variables (Fig. 3). Age and country were among the most influential aspects for waste management, energy saving, and sustainable consumption ($p \leq 0.001$; $\chi 2 = 100–1000$). Respondents from Spain and Portugal strongly indicated the use of fewer COVID-19 tests, whereas people from Slovakia and Greece indicated a high testing rate: with more than five tests per person, on average, since the beginning of the pandemic (Q8; Supplementary material 2). In addition, younger respondents (people from 18 to 35 years old) took more tests. Less frequent use of face masks was detected in Mexico and Slovakia than in Spain, Portugal, and Greece, where a large number of face masks were used monthly (Q9; Supplementary material 2). Some respondents, especially younger ones, reported using washable masks. Greece stood out in the use of disposable products (Q10), as participants there indicated that they used the same amount before and during the pandemic. However, in Spain, a great number of surveyed respondents indicated that they did not use disposable products.

Shopping/consumption habits (Q24) were independent from employment situation ($p \leq 0.05$; Fig. 3).

All of the socio-demographic groups reported that their travel behaviour (Q13 to Q16) was largely affected by the pandemic ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$; Fig. 3). How respondents travelled to work was the variable (Q14) that was most strongly affected by the country and employment situation ($p \leq 0.001$, Fig. 3), showing greatest changes in Spain and Greece (Supplementary material 2; Q14). Most respondents indicated that they did not change their usual transportation modes due to the pandemic ($p \leq 0.001$, Fig. 3). Of the responses reporting no effect of the pandemic on habitual modes of transport, the frequencies of transport modes still depend on employment status (private transportation: Supplementary material 2; Q14).

The perception of gender and social inequalities (Q17 to Q19) was strongly related to all socio-demographic aspects studied ($p \leq 0.01$ and $p \leq 0.001$; Fig. 3). Both varied widely by country, age, and gender. Although most respondents agreed that the pandemic had affected all sectors of the population equally, it is noteworthy that the older people were considered as the most affected by the pandemic from the perspective of respondents from Portugal and Spain (Supplementary material 2; Q17).

The perception of noise reduction observed during the pandemic was related to all the socio-demographic aspects included in the surveys ($p \leq 0.001$; Fig. 3), except for gender and knowledge area. Mediterranean countries, including Spain, Greece, and Italy, as well as India, indicated the perception of a decrease in noise (Supplementary material 2; Q21). This decrease was less noticed by young people (18 to 25) compared to the rest of the surveyed population (Supplementary material 2; Q21).

Generally, the perception of the environment, nature (Q25 to Q31 and Q34), and the human perception towards the pandemic and the future (Q28, Q32 and Q33) showed significant effects ($p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$). The respondent's country of residence showed the greatest significant effect on the responses ($\chi 2 = 100–1000$, $p \leq 0.001$; Fig. 3). Regarding visits to natural spaces during the pandemic (Supplementary material 2; Q26), Greeks and Slovaks indicated a greater use of natural spaces with respect to the other respondents. Specifically, the questions about the improvement of the situation for 2021 (Q31), were the least affected by the socio-demographic aspects studied but highly affected by the country. The respondent's country was the most influential aspect in the opinion that COVID-19 has benefited to the environment (Q27), and Spaniards and Greeks more strongly indicated benefits of the pandemic (Supplementary material 2; Q27).

Human perception towards the pandemic was significantly affected by most of the socio-demographic aspects we studied ($p \leq 0.05$; Fig. 3). In particular, social perspective varied noticeably among the knowledge areas with the lowest p-value for the importance of the tourism reduction in cities (Q28).

3.4. Comparison of the situation before and during the lockdowns

3.4.1. Quantitative changes in travel by plane, consumption habits and visits to natural areas

Our quantitative assessments suggest that travel by plane and the number of visits to natural and/or semi-natural spaces significantly decreased due to the pandemic ($p \leq 0.001$), while online shopping increased (Fig. 4).

3.4.2. Interaction between qualitative demographic variables and changes in travel by plane, consumption habits, and in the number of visits to natural areas

Supplementary material 3–5 shows how respondents changed some habits (number of airplane trips, purchasing behaviours, and number of visits to natural areas) associated with the qualitative demographic variables, due to the COVID-19 outbreak.

a) **Intensity of changes in travel by plane (frequency of airplane travels)**

Travel frequency was reduced in two categories in most cases and one category in some cases (Supplementary material 3).

In Mediterranean countries, the airplane trips among people under 65 years old were particularly reduced in Greece and Spain (Supplementary material 3, Fig. Sa). Italy showed the same change for respondents between 18 and 35, and Portugal showed this change for people between 26 and 65. Mexico only showed a reduction in airplane trips for people between 36 and 50.

Overall, for all studied countries, the factor of parental situation concerning age did not seem to affect the reduction in the travelling frequency by plane, while the employment situation and field of knowledge did (Supplementary material 3 Fig. Sc). Unemployed people between 36 and 50 showed a smaller change in their travel frequency than the surveyed students and employed people, with students under 25 showing less change. People aged 51–65 involved in arts and humanities disciplines showed a lower decrease in their trips than those in other knowledge areas. Conversely, people in the health sciences field showed a higher reduction in their travel frequency.

Respondents involved in “arts and humanities” from Portugal and Mexico reported a smaller reduction in travel frequency, and Mexican respondents in “engineering, architecture and health sciences” showed a lower reduction than respondents in sciences and social sciences and law (Supplementary material 3, Fig. Si).

b) **Intensity of changes in consumption habits**

In all of the cases studied, respondents increased their purchases in at least one level of intensity (Supplementary material 4).

Regarding the age of the respondents, the greatest changes were observed among 25–50 years old age groups, while the lowest was among younger age groups. Specific interactions with the country were observed in Greece, Portugal, and Mexico, where habitants in the 18–35 age class showed the lowest increase in their purchasing (Supplementary material 4, Fig. Sa). Only women aged 36 to 50 showed an increase in their purchasing frequency in comparison with the rest of the age classes and genders (Supplementary material 4, Fig. Sb). According to parenthood, only people aged 26 to 50 with children increased their purchasing habits compared to respondents without children (Supplementary material 4, Fig. Sc). Concerning employment status, active workers (“employed” and “student and employed”) intensified their consumption during the pandemic, compared with unemployed people (Supplementary material 4, Fig. Sd).

Concerning the country of residence, males from Portugal and

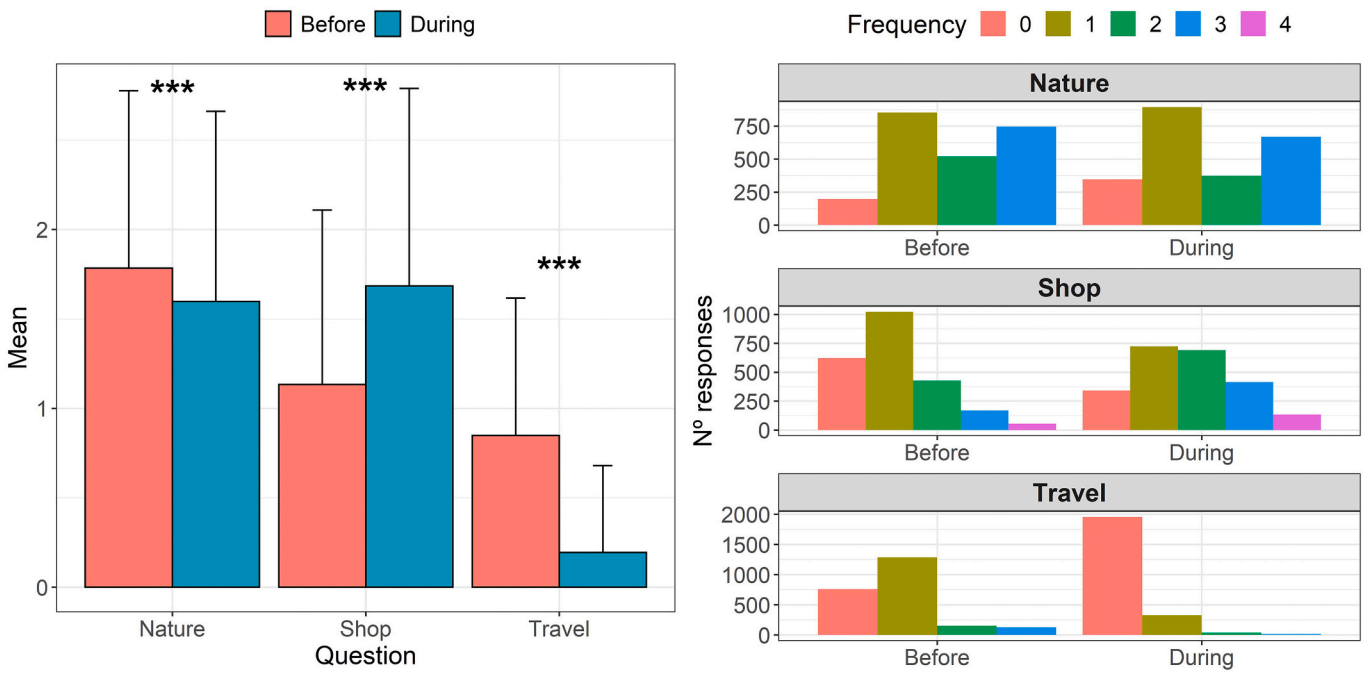

Fig. 4. Comparison between the number of visits to natural areas (nature; Q25–26), purchasing behaviour (shop; Q22–23), and travel by plane (travel; Q15–16) before and during the pandemic. Overall results on the left plot, and results detailed per responses on the right. $N = 2370$, $p \leq 0.001$ (***) by paired Mann-Whitney-Wilcoxon tests.

Greece did not change their consumption, but females experienced a greater change. Mexican and Portuguese people with children were the ones showing the greatest changes in their consumption habits, while for Greece, no interaction between parenthood and country in purchasing behaviour was observed (Supplementary material 4, Fig Sg).

According to gender, overall females were the ones increasing their consumption compared to men. Also, parenthood status influenced shopping habits, with females with children being the only ones increasing their habits compared to females with no children (Supplementary material 4, Fig. Sj). Also, females with income ("employed" and "student and employed") expressed a higher increase in purchases (Supplementary material 4, Fig. 7 k), particularly those in the knowledge area of "health sciences" (Supplementary material 4, Fig. Sl).

c) **Intensity of changes in the number of visits to natural areas**

Despite an observed general reduction in visits to natural areas (Fig. 4), in most cases, this change was not as intense as changes in travel frequency (Supplementary material 5).

With respect to age, the most noticeable change was observed among Mexicans aged 18–25 and 51–65 who reported a decrease in the number of visits to natural areas, and the same change was experienced by young Portuguese (Supplementary material 5, Fig. Sa).

With respect to country of residence, respondents identifying as women from Portugal and Mexico reported a greater reduction in their number of visits to natural areas in comparison with men (Supplementary material 5, Fig. Sf). Regarding parenthood and country interaction, Portuguese with children showed a lower reduction in their visits to natural areas than Portuguese without children, and no interaction between parenthood and country was detected in Mexico, Spain, and Greece (Supplementary material 5, Fig. Sg). Mexican and Portuguese belonging to the categories Student and Employed and Student showed a notable reduction in this habit (Supplementary material 5, Fig. 8 h). People from Portugal and Mexico involved in "health sciences" and those Mexicans related to other Sciences disciplines showed a drastic reduction in their number of visits to natural areas (Supplementary material 5, Fig. Si).

Noticeable interactions were not detected with visits to natural areas for respondents representing different genders, parenthood status, employment situation, and knowledge area (Supplementary material 5, Fig. Sj-o).

4. Discussion

4.1. New perceptions and attitudes of the population due to the COVID-19 pandemic

The most alarming consequence of the pandemic, from an environmental point of view, was the unprecedented large amount of waste generation (medical and nonmedical) which has long-term consequences and unsustainable environmental impacts (Zhang et al., 2020; Klemeš et al., 2020; Rupani et al., 2020; Wang and Su, 2020). This situation was more acute in those countries that had already included the reduction of single-use products in their sustainable agendas before the pandemic, e.g., countries of the European Union, China, Canada, United Kingdom, etc. (Shams et al., 2021; Liu et al., 2020; UNCTAD, 2022, Benson et al., 2021). Although this fact has been previously reported, it is paradoxical as the perception of the population sometimes does not coincide with reality since most of the respondents declared to have used fewer single-use products during the pandemic. This can be used by governments to implement new measures to decrease the use of these products. In the same way, although our participants perceived that their purchasing behaviours were the same, the resurgence of e-commerce has negative impacts through the production of waste products, and competition with local commerce, leading to a reduction in local incomes (Cruz-Cárdenas et al., 2021). Respondents perceived the reduction in tourism traffic as another key weakness. However, an opportunity which emerged was to development of sustainable transport infrastructure with associated economic benefits: most respondents also believed that their countries should have focused on more sustainable jobs, e.g., green jobs to solve this pandemic. The United Nations has argued that green jobs are "the only way to go" (https://www.un.org/en/). The independent WWF agrees, indicating that new nature-based policies are vital (Lieuw-Kie-Song and Pérez Cirera, 2020).

Conversely, reduced amount of physical commuting have encouraged new working habits that may positively impact the environment if maintained in the long term (Crowley et al., 2021), which could be a potential strength. Previous studies have indicated that working remotely, working from a home-office, and telecommuting are part of a more productive work model that also improves work-life balance (at least for some workers) and can contribute to reduce transport flows (Hunter, 2019; OECD Policy Responses to Coronavirus (COVID-19), 2020; Morikawa, 2020). The reduced number of commuting trips mean less traffic congestion and air pollution, in particular during peak times, since the transpor sector is the largest contributor to urban air pollution (Hunter, 2019). However, about one third of respondents still commuted to a workplace (until September 2021), and the majority of respondents indicated that they did not change their transportation mode due to the pandemic, with private vehicle use still being prevalent. There is also a potential that remote and hybrid work schedule, in the long run, might hurt public transport ridership, as this is usually designed in particular to serve commuting trips during peak times on major commuting corridors. Not surprisingly, in many larger US cities, public transport ridership continued to remain below pre-pandemic levels as workers resumed activities, with the demand for car travel rebounding much faster than that for public transport (Soza-Parra et al., 2022). Our results confirm a consistent excessive use of private vehicles even during the pandemic (Gkiotsalitis and Cats, 2020; Thombre and Agarwal, 2021) indicating that people make their travel choices based on different criteria, such as time, cost, convenience, safety and reliability (Sharifi, 2022). Again, the role of governments in providing a sustainable transportation network is key in promoting this change of habit into more sustainable transportation modes. While some studies have pointed to the relative increase in popularity of active modes of travel (e.g. walking and cycling) during the pandemic, many of these changes proved to be only short-lived (McElroy et al., 2022). In this sense, several countries (e.g., Spain, USA) have regulated and updated labour laws to adapt to the pandemic towards promoting more remote or hybrid works, posing an opportunity for positive environmental impacts (Galanti et al., 2021). Applications of smart city solutions and technologies could offer new opportunities for reducing mobility even when the COVID-19 pandemic ends (Sharifi and Khavarian-Garmsir, 2020; Sharifi, 2022).

Many survey participants detected reduced environmental noise levels (strength) during the pandemic, as also reported by Zambrano-Monserrate et al. (2020) and Somani et al. (2020). Even so, it is important to note that after the lockdown many actions such as hotel business, traffic, and leisure activities, have moved outdoors due to the pandemic, potentially resulting in a new threat to the urban environment such as greater noise levels. Indeed, this flux of outdoor visitors may present a new threat to nature.

As most survey respondents perceived, strict lockdowns reduced air pollution, improved air quality, and decreased noise levels, which had an important positive environmental impact (Prakash et al., 2021). However, these short-term positive impacts were strictly derived from the lockdown restrictions on human travels and they disappeared as soon restrictions were lifted (i.e. Nilashi et al., 2019; March et al., 2021; Millefiori et al., 2021). This positive perception by the respondents may constitute an opportunity and should motivate governments to implement new measures to decrease pollution (chemical and noise) in the environment; in fact, respondents considered (in Q32) that now is the time to act due to the shock situation promoted by the pandemic. Governments should also be encouraged to implement new public policies to reduce pollution and face global change, simply because multiple threats such as the pandemic can interact with other drivers to global change and reduce the trajectory towards more sustainable futures (Garrido-Cumbrera et al., 2021; IPCC, 2021; Bates et al., 2021b; Nahm et al., 2022).

Another noteworthy aspect is the importance that has been attributed to natural spaces. Our results showed that the short-term positive environmental effects of the COVID-19 pandemic have been noticed by the population because our respondents indicated that COVID-19 has benefited the environment (Q27). According to our survey, most people are now aware that environmental changes are possible if the population alter their habits. This constitutes an opportunity to promote new politics to achieve more sustainable and greener cities following the concept of "Endorsement of Green Recovery" (Bashir et al., 2020; Kumar et al., 2020; Lal et al., 2020; Lutu et al., 2020).

4.2. Effects of socio-demographic aspects on behavioural variables

The effect of the country detected on waste management (i.e., number of COVID-19 tests used, number of used masks, or number of disposable products used) reflected the results of the government restrictions enacted to deal with the COVID-19 pandemic, along with cultural. For example, in Greece, many tests were conducted during the exact time of the current study for travellers who wished to enter the country, regardless of their vaccination status (https://travel.gov.gr/, last access 20 January 2022). It should be noted that the timing of the survey is crucial, as the use of COVID-19 tests has likely increased since we took the survey. It is important to consider that Peng et al. (2021a) calculated the excess generated of municipal mixed plastic waste (MMPW) during the pandemic as 4.4 million to 15.1 million tonnes, indicating an excess of waste from the use of masks, tests, etc. This excess of waste is considered as a new and important emerging negative impact in this situation that should not go unnoticed.

Although many respondents indicated that they used washable masks (Q9), a large number of responses were obtained in the category of "more than 20 disposable masks" per month, demonstrating that masks are one of the next waste problems, as some works have already indicated (Jimoh et al., 2023; Xu and Ren, 2021). In addition, the greater use of washable masks was detected in countries with lower income, such as Mexico and Slovakia, indicating that the use of masks is maybe more related to socioeconomic variables than environmental attitudes. Moreover, the higher use of washable masks was detected among young people and could be related to the lower income of this segment of the population with younger people being more likely to use less effective masks.

The low use of single-use products reported by survey respondents stands out and contrasts with published reports that single-use products were used more often during the COVID-19 pandemic (Klemeš et al., 2020; Rupani et al., 2020). This may be explained by the fact that these studies have considered masks as one of these products, and we placed the use of masks in a separate section of the survey to distinguish them from the other sources of single-use products. Moreover, some governments have regulated the prices of masks, in particular, controlling prices for KF94 surgical masks (e.g. Dae-Yong, 2021), which led to a price reduction for disposable masks; hence, their consumption has increased. However, this occurred after the time of the survey, and for that reason, we could not detect the possible effect of the reduction in prices regulated by governments (country) on the use of masks.

Participants perceived that their purchasing behaviours were the same during lockdown periods, while our results show that online shopping has modestly increased due to the pandemic effect with significant differences between countries (Supplementary material 1; Q24). For instance, respondents from Spain and Portugal have increased their e-commerce more than others with a lower Consumer Price Index (CPI), such as Mexico (https://en.www.inegi.org.mx/temas/ppc/). Nevertheless, countries with lower purchasing power, such as Greece, also increased their online purchases, demonstrating that habits have changed due to the pandemic, independent of purchasing habits or gross national income. The increase in online shopping was relevant among young people, highlighting an emerging tendency for younger generations to consider. Online shopping is one of the most relevant online activities, making important contributions to the global economy (Cai and Cude, 2008; Steinfield et al., 1999). But a disadvantage related to e-commerce activity is the creation of impulsive consumers, with

important consequences to the environment (considered to be a negative behaviour) (Beatty and Ferrell, 1998).

As for mobility and sustainable transport, Spain and Greece stand out as the countries with the greatest number of people working physically and travelling to their workplace despite pandemic restrictions. Spanish and Greek respondents indicated that they mostly use private transport. In addition, the use of public transportation is restricted to that specific country or even restricted to a particular city. It seems that the employment situation affects the way people get to the workplace observing a higher use of private vehicles by employed people (people with higher purchasing power). Hence, governments in Spain and Greece ought to support employees more in order to improve access to reliable and efficient public transport.

Concerning gender and social inequalities, the effect of the interactions among different countries, ages, and genders, gives a clear indication that policies are very important. In most surveyed countries, most people stated that older respondents were the most affected by the pandemic. In contrast to these opinions, a recent report from United Nations Foundation, (2020) argued that domestic violence spiked during this "shadow pandemic", as girls and women sheltered in place with their abusers, women lost jobs, and the world's nurses (a female-dominated profession) shouldered tremendous risks and burdens, and the unpaid care work mostly provided by girls and women. Even so, participants who identified as either male or female claimed to be more affected than their respective counterparts (Supplementary material 1; Q17).

Although most socio-demographic aspects influenced the perception of noise generation, the role of the country of residence and its cultural aspects emerged as being significant. The findings obtained by Garrido-Cumbrera et al. (2021a) suggested that the positive impacts on the natural environment, including noise reduction, as a result of the lockdown were better received by the populations of Spain and Ireland. In Mediterranean countries such as Spain, Greece, and Italy, the noise level is high due to most people living in flats, and a high percentage of their household expenditures are devoted to restaurant services (Eurostat, 2018). For this reason, lockdowns made the noise reduction more noticeable in these countries.

People with scientific backgrounds might better understand the environmental situation and social responsibility during the pandemic and in the future. Having a scientific background could therefore be an influential factor, although it showed a lower effect than expected. But socio-demographic aspects do have a clear effect on perceptions that COVID-19 positively affected the environment. This aspect was also detected by Garrido-Cumbrera et al. (2021), who considered the pandemic to be an unprecedented opportunity to raise awareness of the effects of human activity on nature and to reduce pollution in the long term.

The perception that "the pandemic has had a positive effect on the environment in general" (Supplementary material 1; Q27) was especially high among Spaniards, although they did not expect the positive effects to last; this perception also prevails among people from other countries. However, the negative effects of the pandemic may be longer-term, and neither the negative effects or their consequences seem to be perceived by the public (Cheval et al., 2020; Rume and Islam, 2020; Garrido-Cumbrera et al., 2021; Peng et al., 2021).

Human perception towards the future and towards the pandemic were mainly affected by the country under consideration. All countries detected an impact due to reduced tourism (Supplementary material 1; Q28). Respondents from countries with a high dependence on tourism, such as Spain, Portugal, and Greece, indicated an important negative impact due to reduced tourism during the pandemic. However, this did not extend to the respondents from Italy, despite tourism being one of the most important industries for the country's economy (https://www.oecd-ilibrary.org/sites/3d4192c2-en/index.html?itemId=/content/component/3d4192c2-en). This can be explained by the high importance granted to health during the pandemic.

4.3. Comparison of the situations before and after the lockdowns

In general, concerning travel behaviour, most people reported a reduction in their trips due to the restrictions' governments imposed to minimize social and physical interactions. However, this reduction can be considered only in the short term, as it does not necessarily imply a persistent change in people's travel habits. The effects of country of residence on the changes in travel behaviour for the surveyed Mediterranean countries (Spain, Greece, and Italy) were similar, but countries such as India and Mexico did not show changes. Generally, people from India and Mexico spent little money on travelling like generally happen: only people aged between 36 and 50 years reduced their trips, possibly related to business or work. Unemployed people between the ages of 36 and 50 showed less change than the rest of those surveyed, indicating that employed people had travelled more than the rest due to greater purchasing power but were more affected by the pandemic.

Online shopping also varied by country and among demographic groups. Mouratidis and Papagiannakis (2021) analysed online shopping habits in Greece and detected a modest increase in this habit, and we detected similar behaviour in our results from Portugal and Mexico. Dittmar et al. (2004) associated women's online buying with barriers (social–experiential factors) and facilitators (efficiency, identity-related concerns) grounded in their attitudes towards conventional buying, but other works indicated that women liked to shop more than men (Vijaya lakshmi et al., 2017). Obviously, people with children showed an increase in their online purchasing habits due to the need for child-care products and additional restrictions when shopping.

Although many recent studies during the pandemic argued for the possible existence of the phenomenon of the "Endorsement of Green Recovery" and an increase in the appreciation of urban green spaces (Lal et al., 2020; Lutu et al., 2020; Ugolini et al., 2020; Zhu and Xu, 2020), our results were in contrast to this sentiment due to the observed reduction in the visits to natural areas. Respondents did not significantly increase their contact with nature and drastically reduced their visits to natural or seminatural spaces, which implies a different approach and adoption of attitudes that do not support acquaintance with or promotion of the environment (Kanelli et al., 2021). Again, the perception of the respondents did not coincide with the reported frequency of visits to green areas. This fact may be due to the timing of the survey dissemination: most of the countries surveyed had mobility restrictions, so visiting natural areas was not within people's reach. Another possible explanation, as Maltagliati et al. (2021) also indicated, is that the closure of leisure and entertainment facilities has caused many people to reduce their (already normally limited) physical activity in outdoor natural environments. Some authors such as Cheval et al. (2020) evaluated the current situation produced by COVID-19 as an opportunity to improve the natural environment, with Zhu and Xu (2020) demonstrating a positive relationship among green spaces, health, and well-being, and Garrido-Cumbrera (2021a) showing an increased appreciation for urban green spaces during the first wave of the COVID-19 pandemic. Indeed, is important to understand the main factors influencing people's attitudes towards biodiversity-friendly greenspace management. Understanding how the different social and cultural background variables aid the better design and management of biodiversity-friendly greenspaces, is thus critical for successful biodiversity conservation in cities and natural areas (Fischer et al., 2018a, 2018b).

4.4. Limitations of the study

The study was limited to people who had direct access to the internet or were approachable by email. The ability to use English was important for countries where the survey was not translated to the official language, such as Greece and Slovakia, even though we do not expect this to yield a considerable bias. While efforts were made to recruit a large enough sample of respondents, and with varied sociodemographic, and the sample distributions are not far from those of the populations of the

countries of interest, the use of non-probability-based sampling, and convenience sampling in particular, somewhat limits the ability to obtain more representative results to the entire population. Many people had a higher level of education, and may not represent a complete sample of the whole country. Although the sample size of our study was large, we obtained relatively more responses from countries such as Spain, Greece, Portugal, and Mexico. We expect that this, to an extent, might have also been reflected in the awareness, attitude, and perceived environment of the included respondents.

5. Conclusion

The results of our study provide insights into the individuals' perception of the effects of the COVID-19 pandemic on the environment, confirming the social vision towards improvements in environmental quality. The novelty of this work relies on being able to capture a mismatch between individual perceptions and the reported data by the literature related to visits to natural areas, generation of waste, etc. Specifically, the observed changes in perceptions and/or attitudes during the COVID-19 pandemic represent an opportunity to improve the environmental quality of many countries worldwide and to transition towards greater respect for the environment. Others however, could constitute a threat in the achievement of the principles of sustainable development.

The increase in COVID-related waste, along with the increase in online shopping, is producing an increase in consumption that results in increasingly unsustainable resource use and waste production (somehow exacerbating existing unsustainable patterns from before the pandemic). This increase in waste in combination with the development of new economic models can be unsustainable for small businesses and represent activities that could have irreversible negative consequences for our planet in terms of waste production.

While this pandemic has had significant negative health and economic consequences worldwide, our findings demonstrate new human habits and behaviours that may negatively impact the environment in the near future if government policies and decision makers do not address them at national and international levels. We further identify emerging perceptions about the environment and ecosystems, and the consideration of respondents about the need to implement new and more sustainable jobs. Such perceptions represent a unique window of opportunity to reinforce environmental protection policies which respect our cities and environmental spaces, but also promote positive human interactions with green spaces. In addition, the increased remote working patterns, new technologies and subsequent reduction in the use of transport (though the latter change has already largely reversed, at the time of writing of this paper) could provide an opportunity to reduce greenhouse gas emissions that is urgently needed to protect life as we know it on Earth.

Despite this study was elaborated with responses from some of the most affected countries by the pandemic, slight variations in the results could be expected in other countries. Therefore, future research should attempt to include a broader geographical coverage to check for possible differences in the results.

Credit authorship contribution statement

NHT: Conceptualization, Methodology, Validation, Visualization, Writing – original draft. AP: Conceptualization, Statistical analysis, Writing – review & editing. SR: Conceptualization and Formal analysis. AED: Writing – review & editing and Supervision. Rest of the co-authors: Writing – review & editing, and international survey administration.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix. Supplementary data

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