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Hand drying in public places: Paper towel vs warm air blower, which is best from
an energy and environmental point of view

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Abstract

This study addresses two primary objectives: comparing the environmental impact of paper towels and air hand drying machines throughout their lifecycle, as shown by Life Cycle Assessment (LCA), and evaluating public awareness and willingness to embrace eco-friendly hand-drying methods.

Scientific papers are used to represent the Life Cycle Assessment by collecting data from them. To evaluate the second objective, a survey is created using the data gathered from the papers. Data analysis is performed in Excel to create correlations and compare the answers.

The scientific papers' findings highlight that paper towels (PT), regardless of material, have the most substantial environmental impact, while hand drying machines (HADM) offer greener alternatives. The survey reveals that demographic factors, such as education and generation, have an influence on knowledge about hand-drying methods, and a significant proportion of the population is open to modifying behaviors for enhanced energy and environmental outcomes.

The study concludes that paper towels are much more harmful, and the public's receptiveness reflects an increasing awareness of the European Union's Green Plan objectives for 2050. Overall, this research yields valuable insights into the environmental ramifications of hand-drying methods and public inclinations toward adopting more sustainable practices.

Keywords: Paper towels, hand air drying machine, environment impact, energy consumption, population survey, population willingness, population knowledge, objectives 2050.

Preface

I would first like to thank Professor Roland Forsberg for bringing this topic to my attention, as well as the course coordinator Ida Johansson.

I would also like to thank my family and friends, who are always there for me in times when pressure is high, and they always show me that I can count on them even if they are far away.

Nomenclature

Life Cycle Assessment – LCA

European Union – EU

Paper towels – PT

Virgin Paper towel – V PT

Hand air drying machines – HADM

Cumulative energy demand – CED

Greenhouse gasses – GHG

Hands under dryers – HU

High-speed hands under dryers – HSHU

End of Life – EoL

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1 Introduction

1.1 Background

The contemporary energy landscape presents an essential and complex challenge worldwide, being affected daily by a unique interplay of geopolitical, economic, technological, and environmental factors. In the 21st century, humanity faces a critical turning point concerning the need to meet an escalating energy demand due to population growth and economic development, all while addressing climate change consequences and the urgent call for sustainable energy practices. [1] Striking the delicate balance between ensuring secure, accessible, and cost-effective energy supply and mitigating greenhouse gas emissions has become an overriding objective. Within this context, a comprehensive and multidisciplinary analysis of existing energy systems, energy policies, and technological innovations proves indispensable to tackle current challenges and pave the way towards a more sustainable and resilient energy future. [2,3]

Climate change is becoming increasingly prevalent in our lives, we hear about it in the media and the effect it has on our ecosystem and our lives. Due to the escalating concerns, the EU has promoted the 2030 agenda encouraging 'Sustainable Development Goals' to improve the quality of life of citizens, having therefore measures to reduce the energy expenditure of our society, and seek to reduce energy expenditure in future years. Therefore, the EU is increasingly opting for these objectives and is aware of the benefits that can be obtained at environmental and energy levels if we get used to small changes to improve our quality of life. [4,5]

By recognizing the impact of everyday actions, the population can seek more sustainable activities that can contribute towards the EU's energy and environmental objectives and make a positive impact in daily consumption. The goals that relate the reduction and improvement of our energy system are 7 and 13, being 7 affordable and non-polluting energy and 13 climate actions. As is well known, society is highly dependent on energy, and we often forget where it comes from or how we can reduce its use since it has become normalized to have access to it in a simple and affordable way. [6,7]

The business of the daily routines and hectic lifestyles causes those small gestures that could be helpful in achieving these goals, such as drying hands more effectively are being overlooked. Currently there are several options for drying hands in public restrooms, including the most common mechanisms such as the use of paper towels or hot air hand drying machines. However, both present potential environmental problems that are often overlooked as they are an everyday and short-lived action already included in our routine, and as such many other daily routines that we overlook, which could be modified into more sustainable options. [8,9]

With so much uncertainty about the future of energy and the environmental future in the coming years, this study seeks to make a comparison between the two most common ways of drying hands, paper towels and the use of air dryers. Knowing that both drying methods are already common practices and that the population is used to them, it is possible to carry

out a population analysis at the level of awareness and to understand whether the population is willing to change their usual behaviors in order to meet the 2030 objectives. [6]

Therefore, the main motivation of the study is to be able to correctly look at and analyze scientific papers that evaluate which way of drying hands can be better on environmental and energy levels, since society is usually not aware of the consequences of routine actions. Another motivation is the future awareness of the population, as this study aims to demonstrate how we can individually help to improve society, even if it is only with small gestures.

It is therefore understood that this work aims to encourage both the reader and all those who have been involved in the process of this work, to create constructive criticism about their way of dealing with the climate crisis and how changing small habits can contribute to society so that we can have less energy dependence and improve the environment in which we live.

Through this review, the aim is to provide a comprehensive and up-to-date overview of the environmental aspects related to hand drying according to publications of scientific papers, providing relevant information that can guide decision-makers and users in choosing more sustainable and environmentally friendly options. By better understanding the full impact of these practices, it will be possible to make informed decisions and move towards a more sustainable and responsible future for hand hygiene in public spaces.

Hand drying methods in public places include paper towels, air dryers, jet air dryers, and it is very common to see at least one of these in a public restroom, and it may even be feasible to have two of these drying methods in the same restroom.

1.2 Aims

1.2.1. Overall aim

The work aims to analyze and compare which of the two ways of hand drying in public places is more harmful to the environment and has a higher energy consumption, thus moving away from the targets promoted by the EU for the 2030 agenda.

It will then focus on whether the population is aware that one of the options pollutes more than the other and whether they would be willing to use the less polluting option going forward.

To this end, this paper pretends to use previous scientific papers in order to form a LCA (Life Cycle Assessment) of the two hand drying methods to obtain a first result, which will then be used to understand how aware society is of hand drying. And use the survey and Excel to analyze the responses collected to analyze if the population is conscious of the energy situation of paper towels and hand air drying machines.

1.2.2. Objectives

The following objectives have been set with the intention of developing and analyzing them in depth in this work in order to achieve the aim proposed.

The first objective is: To analyze and compare the energy consumption and environmental impact of paper towels and air hand drying machines throughout their lifecycle, from their raw materials to their disposal.

- How much environmental pollution do they cause?
- Which drying method is most energy-intensive?
- At what point in its lifetime does it pollute the most?

With this information gathered the intention is to clearly show what scientific papers have said about LCA of paper towels and had air drying machines, giving all the data needed to create a comparison between both of them and evaluating which is worse environmentally and energetically speaking.

The second objective is: To evaluate the public's awareness regarding the environmental impact of both drying methods and to determine their willingness to adapt their routines for reducing energy consumption in favor of a more environmentally friendly option.

- Are they willing to change their habits to improve the energy and environmental situation?
- Are they aware of which option is more polluting?
- Do demographic factors such as age, education or location influence whether they want to change their habits for the better?

The survey of the second objective is related to the first one, as it is important to relate the information gathered in first place to create a meaningful survey that can be used to understand what society thinks about the methods of drying hands, if it could be a useful way to save energy and reach the Agenda objectives, and if so are they willing to adapt to changes.

Using these objectives (and the subsequent questions from each of them) as a guide for the work, the aim is therefore not only to cluster and analyze the data obtained from other sources about the LCA, but also to evaluate and inform society that we can contribute to improving our society in a simple way and with few changes in our routine.

1.3 Approach

The study will answer two objectives using different approaches and data sources. The first objective aims to use previous papers to compare the environmental impact of paper towels and air hand drying machines throughout their lifecycle, using qualitative research by recollecting data from scientific papers. The second objective assesses public awareness and willingness to adopt eco-friendly hand-drying methods through quantitative surveys. The

surveys will provide inhabitants opinion and Excel will be used to create correlations between each answer of the survey. Demographic factors like age, education level, and location will also be analyzed. [10]

2 Method

In order to answer both objectives of the study, each of them have been answered following a different approach as the information collected comes from different sources. It is therefore determined that as both have a different focus, it is best to give them a different approach when answering them, not only to collect a more accurate and full response, but also to use different methods of analyzing data.

2.1 Study object

Regarding the first objective ("To analyze and compare the energy consumption and environmental impact of paper towels and air hand drying machines throughout their lifecycle, from their initial use to their disposal"), the aim has been to explore the functioning of both hand-drying methods by looking at scientific papers and subsequently analyze and compare their environmental and energy-related aspects.

The scientific papers consisted on peer papers as well as journals, articles and catalogues from different institutions and businesses, in order to provide a full understanding of the different backgrounds that the information can come from.

As for the second objective ("To evaluate the public's awareness regarding the environmental impact of both methods and to determine their willingness to adapt their routines for reducing energy consumption in favor of a more environmentally friendly option"), this objective has sought to gauge the public's opinions and willingness to adopt a less harmful hand-drying option.

The study object have been the survey contestants, by evaluating them through an online survey and collecting their answers about how well informed they are about the hand drying methods and their consequences to the environment.

2.2 Procedure

To achieve the first objective, qualitative research using literature review has been employed initially. This approach allows us to gather expert insights on how both drying methods function and understand their lifecycle. It has been essential to establish a clear understanding of how each method affects the environment and energy consumption before proceeding with further analysis. Subsequently, the information gathered from the scientific papers presented on 'Literature Review' has been presented on Table 1, allowing all the main results to be accessible and be easily understood.

The process of gathering scientific papers involved a structured approach, primarily conducted through the research platform ResearchGate. Initially, the research focused on internet sources, encompassing journals, scientific reports, government reports, and business reports, including those from companies such as Dyson. To facilitate this search, a

set of specific keywords, including 'paper towels,' 'environment,' 'hand drying,' 'energy,' 'types of drying methods,' and 'eco-friendly,' was systematically employed as part of the inclusion criteria to identify pertinent scientific papers.

Following this comprehensive search on ResearchGate and other relevant sources, a meticulous selection process was implemented to curate papers containing information directly aligned with the research objectives. Papers diverging into areas unrelated to the core aims of the study, such as those exploring the effects of bacteria in the drying process or addressing hygiene-related aspects, were deliberately excluded. This exclusion was based on the stringent criteria established to maintain the study's focus on the predefined research goals.

By identifying the key information of the data collected, it has been identified the stages of each method's lifecycle that have the most significant environmental impact, which include:

- Materials - which take into account the raw materials that are being used in order to produce the product (the product meaning the PT and the HADM)
- Manufacturing - the process in which the raw materials are converted into the product itself that can now be used
- Transportation - any type of transport that the product needs between and within each phase of the life cycle
- Use - consumption or emissions during the use of the product
- End of life - focuses on how the product is treated after its lifespan, where is going to be deposited and the effects

This presents the entire lifespan of the products, from the production of paper towels and air hand drying machines to their disposal.

The literature review has been extensively used to provide comprehensive insights into the usage of paper towels. This has included descriptions of their production process, distribution, and proper disposal after use. Similarly, the same approach has been applied to evaluate air hand drying machines, detailing their manufacturing, distribution, energy consumption during usage, and appropriate disposal once their lifespan ends. This thorough examination has enabled to form an impression of both hand-drying methods and determine which one has a greater negative impact.

In order to analyze the second objective (To evaluate the public's awareness regarding the environmental impact of both drying methods and to determine their willingness to adapt their routines for reducing energy consumption in favor of a more environmentally friendly option) , it has been proposed to do so using quantitative research using surveys of the population. In this way, the aim has been to reach the maximum number of respondents and obtain an analysis of a sample of the population in which the answer to the objective has been sought.

In this second objective the data gathered from the first objective has been used to conduct the questions to be answered in the survey. As there is enough data from the scientific papers regarding the LCA of each product, the conclusion of which of both methods is most prejudicial has been made, and so used in the survey to see the level of knowledge of the population analyzing according to the objective the “public awareness regarding the environmental impact”.

It has also been presented in first case a question in order to evaluate the public understanding on how prejudicial the drying hands methods can be. Afterwards it was presented to them the data collected from the scientific papers in order to evaluate if their response changed once they knew which method is more contaminant and as the objective wants to achieve, see if they have a willingness to change their habits. With no intention of leading the contestants to an answer, only trying to understand if they have a willingness to change their habits and improve their habits. [11]

Therefore, the evaluation proceeded with closed questions (with the option to write a better answer if the available answer options did not satisfy the respondent), which have been created from the conclusions found in the first objective. In this way a part of the population has been also be analyzed demographically using factors such as age, level of education and place of residence.

After the survey was done and the results are were collected, the data gathered was classified using Excel. Correlations were drawn, such as the percentage of persons responding to one answer and presenting profiles of respondents to a particular question.

In order to figure out the profile of the respondent of a question, several steps have been followed. In first place it must be said that the profile of the respondent is related directly to the demographic questions answered, which determined the full profile. Therefore, the three demographic questions (Education level, Generation and Living environment) have been used as well as the response of the question to create a profile of the person who is more likely to opt for one of the answers.

By using Excel, the steps have been as follows. It was classified how many contestants respond to each question regarding each *demographic* question, once this was sorted out relations between the answers of the non-demographic questions available and the answers of the demographic questions have been linked. By using the tools from this program, it has been relatively easy to classify by percentage which group of people (by this it means people that have similar characteristics like the same generation) opt for a specific answer. It was then proceeded to show which group opts for which answer and compared them to see which had a higher percentage, obtaining as so the profile for each question.

2.3 Population of test person

The survey has been conducted online, in order to reach as many people as possible. Twelve questions related to the use of hand drying methods (Appendix A.a.) have been formulated and were based on the previous analysis obtained from peer-reviewed papers and articles related to the topic to be studied. The questions have been formulated in order to avoid

vague answers and offer a wider range of answers. As well as the opportunity to acknowledge any other option if it was necessary. [11,12]

Demographic questions also allow the sample to be segmented into homogeneous subgroups, enabling more detailed and targeted analysis. By comparing responses from different cohorts or demographic groups, significant differences in attitudes and behaviors have been uncovered, enriching the analysis and providing key information for decision-making. [11]

The demographic factors that have been asked in this test are therefore Education level, Generation and Living environment. Three questions have been asked [13]

Demographic question 1- Education level. Which could be answered with the following options :

- Primary education or below
- Secondary education
- Highschool or equivalent
- Medium-grade vocational training
- Professional training of a superior level
- University degree
- Master's degree or higher

This demographic question has aimed to see if the level of education of the population affects the population in any way, as it could be a relevant factor to take into account, since a high level of education could be related at first to a higher level of awareness or a greater willingness to change habits. [13]

This is why this first question is considered, and divided into the options offered, as it is intended to be as precise as possible and to cover as many options as possible in order to have greater precision when analysing the subsequent results.

Demographic question 2- Generation. With the following options:

- Silent Generation (1926-1945)
- Baby Boomers (1946-1964)
- Generation X (1965-1980)
- Generation Y (1981-2000)
- Generation Z (2001-onwards)

This question has aimed to cover the generational level of each respondent, and to compare whether people are more aware of how important it is to reduce energy consumption. Therefore, this option has been considered, with the possible result that some generations

may be more reluctant to change their habits and want to maintain a more traditional way of drying hands, such as the use of paper towels.

Demographic question 3- What kind of environment do you currently live in?

- Urban
- Suburban
- Rural

By asking this demographic question, it was wanted to see if there may be a tendency in more rural areas to have a more reluctant mentality to change the way of drying hands. Or, on the contrary, if air dryers are already in common use, and regardless of where the population lives, the answers from the population are the same. [14]

In addition to the demographic questions and the analysis of these, the aim has been to reach an overall conclusion of the surveyed population, as it is also been intended to see whether people are generally willing to change their behavior and try to improve their habits in order to meet the objectives set by the European Union. The number of people to be surveyed has been calculated according to a method.

Following a confidence level of 95% and taking into account that it was wanted to survey as large a population as possible, it was decided to sample the population such as the city of Valencia of 791413 inhabitants. Therefore, following the procedure for obtaining the necessary number of respondents. [9]

$$95 \% - \text{Punctuation } Z = 1.96 \quad (1)$$

The Z value being the margin of error value of the survey to be carried out. Thus concluding that for an error value of +/- 8% and proceeding to use the formula shown below with a standard deviation of 0.5:

$$\text{Sample size} = ((Z\text{-score})^2 \times \text{Standard deviation} \times (1 - \text{Standard deviation})) / ((\text{Margin of error})^2) \quad (2)$$

An ideal sample size of 151 persons was obtained in order to meet a confidence level of 95% with an error of +/- 8%.

2.4 Ethical considerations

Ethical considerations in the first objective have included, to show the main reasons of contamination according to the scientific papers that have been looked at. It has been taken into account all CO₂ eq emissions of the lifecycle as well as the usage of energy. Possible

effects after the end of life of the methods have been also presented and compared between each method.

Anonymity and confidentiality have been in this case the most important ethical considerations to take into account when doing the population survey. In this case all the data collected from the survey has been only the one answered by the survey contestants, no other information has been gathered. This has offered a confidentiality and anonymity to the contestant, where their answers to the demographic questions have provided the information needed. [14]

The objective of the survey was also clear for the surveyed, as it was explained in the survey that the information collected has only been used for this paper and only for academical use. Therefore, the conditions under which the data has been analyzed and used were presented to them at all times. [12,14]

2.5 Possible limitation of the study

Online surveys also have had limitations, they have become widely used and convenient for data collection, offering several advantages like reaching a broad audience, saving time and quick data gathering. However, it's crucial to recognize that they do have limitations that have been carefully considered to ensure the data's quality and reliability. This paper delves into the primary limitations of online surveys, focusing on issues related to sample bias, non-response, data validity, technical challenges, and the interpretation of open-ended responses. [11]

One limitation of online surveys has been its potential sample bias and representativeness concerns. Internet accessibility and digital literacy vary across demographics, leading to some groups being excluded, such as people with advanced ages which have had a more difficult access to technologies, which has affect the generalization of findings. [11,12]

Moreover, identity verification and duplicate responses are also challenges. Online platforms in this case did not verify respondents' identities, leading to potential duplicate submissions or fraudulent responses that may distort data accuracy. [11]

Open-ended responses present interpretation challenges. Analyzing these responses has been time-consuming, and effort was invested in processing and extracting relevant information. While online surveys offer advantages, they have limitations that were considered. Addressing potential biases and challenges enhances data validity and reliability, making online surveys a powerful tool for gaining insights across fields. [12,14]

Moreover, another limitation appeared with the use of the scientific papers to evaluate the Life Cycle Assessment (LCA). Despite its value, LCA also has limitations that were considered for proper result interpretation and informed decision-making.

A significant LCA limitation has been reliance on available and accurate data for resource consumption, emissions, and environmental impacts, which has been challenging to obtain, affecting precision and decision-making as it is complicated to ensure valid data of the paper towels and the hand drying. Categorizing impacts in LCA has posed challenges, as grouping and classifying environmental impacts can affect conclusions and comparisons. Therefore, transparent selection of impact indicators and weighting has been essential.

Technological changes and industrial shifts can affect LCA results over time, and taking into account that more types of drying machines have been included recently in the market it was difficult to analyze with precision. With data obsolescence necessitating sensitivity analysis and consideration of different scenarios.

Moreover, the geographical and cultural context influence LCA results, with varying energy sources and waste management impacting analysis applicability, as it is not the same to analyze the energy source from Sweden than from the rest of Europe, as they have very different sources of energy production. Nevertheless, LCA has been valuable for environmental impact assessment, but its limitations require recognition and proper attention. Considering data, system boundaries, impact categorization, technological changes, interpretation, and geographical context it has been enable an effective investigation of scientific-papers regarding Life Cycle Assessment and informed environmental decision-making. [15]

3 Results

3.1 Literature review

3.1.1 Overview

The purpose of this literature review is to collect information from scientific papers, journals and articles and compare the energy consumption and environmental impact associated with two common hand drying methods: the use of air hand drying machines and the use of paper towels. To this end, an investigation from the information gathered from the sources of the relevant academic literature on this topic will be carried out, covering the initial manufacturing stage through to the end of life of both options.

The analysis will include the assessment of greenhouse gas emissions, natural resource consumption and waste generation throughout the life cycle of air hand drying machines and paper towels. In addition, it will seek to identify the key factors that influence the environmental impact of each method.

In order to do so, the main results have been presented in several ways such as Table 1 and Figure 1-3 so that the understanding of the information gathered about LCA is much more visual and appealing to the reader. By this means, the data collected from the papers will be presented clearly and remarking the key results of the gatherings.

As a result of continued pollution and advances in technologies, the European Union has launched 'The European Green Pact' in which it aims to achieve climate neutrality by 2050. The target for this year will be net zero emissions, and to this end, targets for 2030 of at least a 55% reduction in emissions have also been set. The literature review is therefore encouraged to assess where the most pollution is produced in current processes and products. [5,6]

Highlighting therefore the goals of the 2030 agenda, number 7 and 13 in which the goals that relate the reduction and improvement of our energy system, being 7 affordable and non-polluting energy and 13 climate actions. Which is directly related to the topic to be studied in this work. [5,16]

Therefore, the management of waste such as PT (paper towels) is increasingly penalized by governments and institutions, as waste such as these cannot be reused or recycled, thus producing tons of waste. Pollution is also clear when using HADM (hand air drying machines), since the energy consumption of these is constant when hand-drying. [17]

Table 1. Table showing the key results regarding each drying hands method according to the basis of the scientific study

			Key results								
Author(s)	Reference		V PT		100% Rec. PT		HU		HSHU		Comments
			CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	
J. R. Gregory, T. M. Montalbo, and R. E. Kirchain, 2013	[18]	Materials: Manufacturing: Transportation: Use: End of life:		3.2 10 1.8 0 0.6		2.2 10.2 1.8 0 0.6		0.5 0.2 0 11.6 0		0.5 0.2 0 7.3 0	Use intensity: PT: 2 towels HU: 20s ± 25% HSHU: 12s ± 25%
Dyson, Inc., Sep. 2011	[17]	Materials: Manufacturing: Transportation: Use: End of life:	263 162 30 0 12	2.9 9.7 1.8 0 0.7	73 169 30 0 22	3.1 9.6 1.8 0 0.9	15 2 1 270 0	0.7 0.2 0.2 16.5 0.2	15 2 1 125 0	0.7 0.2 0.2 6.6 0.2	Additional life cycles: HSDM: packaging PT: packagings, dispenser, waste bin, bin liners
XLERATOR, Excel Dryer Inc. , Sep. 2022	[19]	Materials: Manufacturing: Transportation: Use: End of life:		1220* 2560* 290* 0* 930*		650* 2560* 290* 0* 930*		175* 30* 5* 4220* 0*		175* 30* 5* 1130* 0*	kJ/Use PT: 743 100% Rec. PT: 460 HU: 222 HSHU: 76

			Key results									
Author(s)	Reference		V PT		100% Rec. PT		HU		HSHU		Comments	
			CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage		
R. Brady, Excel Dryer, Inc, Jul. 2010	[20]	Materials: Manufacturing: Transportation: Use: End of life:		1200* 2640* 275* 0* 940*		680* 2640* 275* 0* 940*		150* 25* 3* 4305* 0*		150* 25* 3* 1070* 0*	100% Rec. PT remains above the impacts of the conventional dryer HSHU time use 10-14s	
European Textile Services Association , Nov. 2016	[21]	Production: Transport: Use: End of life:	275 0 0 20	10.2 0.3 0 0.4	252 0 0 43	12.7 0.3 0 0.4					<u>Waste EoL:</u> 100% Recycled paper – 93.3 kg Virgin paper – 67.8 kg.	
Excel Dryer Inc. , 2009	[22]	Materials: Manufacturing: Transportation: Use: End of life:		1220* 2560* 290* 0* 930*		650* 2560* 290* 0* 930*		175* 30* 5* 4220* 0*		175* 30* 5* 1130* 0*	One ton of virgin paper towels consumes 17 trees One ton of virgin paper production pollutes 7,000 gallons of water	
S. H. Budisulistiorini, TEKNIK, vol. 28, 2007	[23]	Materials: Manufacturing: Transportation: Use: End of life:					14 2 1 281 0		16 2 1 121 0		HU electricity used: 1,083 kWh	

			Key results									
Author(s)	Reference		V PT		100% Rec. PT		HU		HSHU		Comments	
			CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage	CED (KJ eq)	gCO ₂ eq per usage		
U. Eberle and M. Möller, Öko- Institut, Jun. 2006	[24]	<i>Production:</i> <i>Transport:</i> <i>Use:</i> <i>End of life:</i>	430 24 0 37	17.3 2.7 0 1.7	390 24 0 37	18.1 2.9 0 1.7					HU time use 15-20s	
Kirschner, J., Lalonde, I., & Bee, S., 2014	[25]	<i>Materials:</i> <i>Manufacturing:</i> <i>Transportation:</i> <i>Use:</i> <i>End of life:</i>		3.8 8.7 2.1 0 0.7				1.2 0.1 0 7.1 0		1.0 0.1 0 4.1 0	HADM- 350,000 uses in its 5-10 year lifetime Manufacturing HADM equals manufacturing 15,000 to 37,000 PT	

- The use of a '*' on the table will indicate the units of the digit will be in kg of CO₂ eq per lifespan

Table 1 shows clearly where the information has been gathered, collecting the main results that involve the LCA of each study and some relevant points that can be used to understand how the methods of drying hands work. The table focuses mainly on the energy and emission of CO₂ eq of each method that is being studied and as seen above, the results vary little between each study and seem to have similar data.

3.1.2 Paper towels

How are they used to dry the hands

The use of PTs is clear and simple, on average a couple of paper towels are used for drying hands after washing in public places. This is usually the most common use for the population, and is the preferred method of hand drying in public places as it is quick, easy and effective. [26,27] It is also a rudimentary method as until the advent of new technologies such as drying machines it was (and still is) the most common way of drying hands, so many people are also likely to continue with the habits they have and continue with this type of hand drying even if air machines are available. [28,29]

LCA of PT

Paper towels can have two origins, recycled and non-recycled, knowing that the majority of paper towel use is of non-recycled origin, where in both cases at the time of using the product the energy expenditure will be zero, since the moment of drying hands does not use energy [21,28]

In the context of paper towels, the manufacturing stage is responsible for more than half of the global warming potential and water consumption. Subsequently, the material production stage and transportation contribute to the environmental impact. Notably, paper towels differ from other products in terms of their significant impact during their end-of-life phase, particularly in terms of the global warming potential resulting from the degradation of these towels in landfills. [30,31]

When looking at greenhouse gas emissions during the production phase, the main culprits are electricity and natural gas use, which together account for about three-quarters of the impact. This is closely followed by the effect of pulp production on the environment. [18,32]

Energy use will depend on the Cumulative Energy Demand (CED), which assesses the total energy required in the total life cycle of the product, in this case virgin paper towels. This will amount to a total of 467 KJ eq, the material and the product manufacturer are the most energy demanding with 263 KJ eq and 162 KJ equivalent respectively, followed by transport and end of life of the product which add up to 42 KJ eq. [18,24]

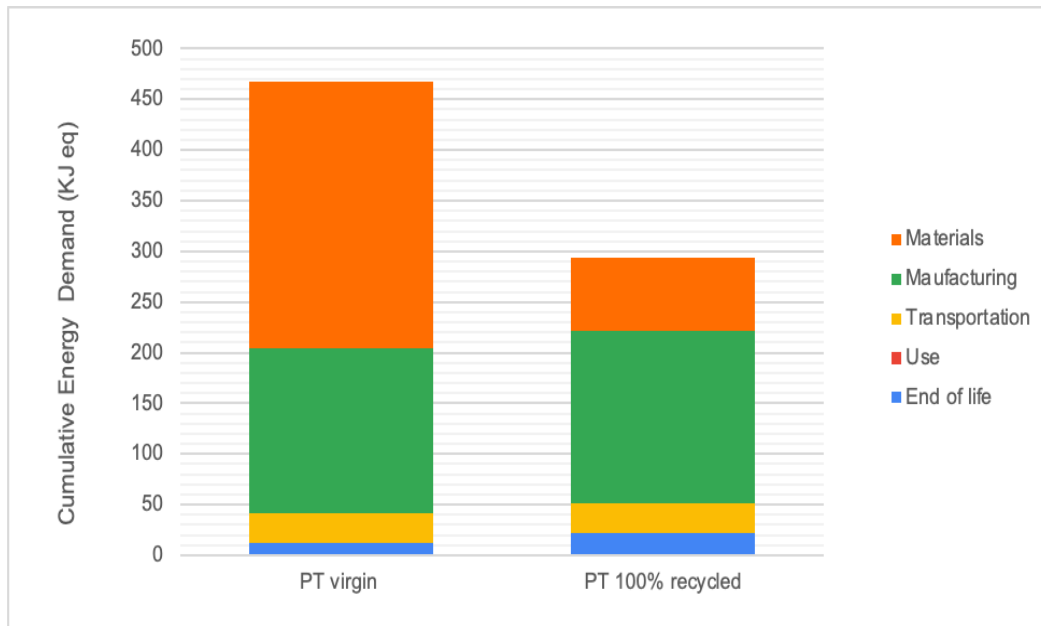


Figure 1. Cumulative energy demand in the lifecycle of paper towels

For 100% recycled towels will have a CED of 295 KJ eq, as a result of the recycled materials, the energy used to obtain the raw materials is reduced significantly being only 73KJ eq. However the manufacturing process continues to be very similar to the one of the virgin PT as it is 169 KJ as seen in the Figure 1, as well as the transportation that is the same being 30 KJ eq. However the end of life of the product is higher than the virgin being 22KJ eq. [17]

According to data collected, to dry a pair of hands a pair of virgin PT will be used, this will result in a use of 15.6 g CO₂ eq. Being the manufacture of the paper towels from the pulp the highest consumption with 10 g of CO₂ eq emissions , raw materials 3.2 g CO₂ eq, transport 1.8 g CO₂ eq and the end of life of the PT 0.6 g CO₂ eq. The use of the paper towels does not produce any greenhouse emissions as it does not use any energy. [18]

The same values for transportation and end of life are applied to 100% recycled PT, however their materials production is significantly less with 2.2 g CO₂ eq, whereas the manufacture of the product remains very similar with 10.2 g CO₂ eq. This results in a total emission of 14.8 g CO₂ eq. [18,24]

Which will produce at the end of the life cycle for virgin towels 47.1 kg of waste, that will pollute the environment . And in case of having a 45% recycled PT 47.2 kg of waste. [15]

Additional impact

The data provided above does not take into account the work it takes to maintain the public restroom clean and tidy, this means that in addition to these numbers it must be taken into

account the cost of cleaning the bathrooms and the additional usage of the waste bins that has not been taken into account. [8,33]

3.1.3 Air hand drying machines

How are they used to dry the hands

The use of a hand dryer machine is very simple and has few steps to follow. First, approach the hand dryer, which is typically positioned near sinks in public restrooms. If the hand dryer is equipped with an automatic sensor, simply move your hands closer to the unit, and it will start automatically, detecting your hands under the airflow. However, some hand dryers may require manual activation, in which case, locate the power button near the airflow outlet and press it to start the drying process.

Once the dryer is activated, place your hands under the airflow nozzle, ensuring they are positioned properly to receive the airflow on both your palms and fingers. After you have finished drying your hands, remember to turn off the hand dryer if it is not automatic, using the power button. Additionally, before using the hand dryer, you may choose to shake off any excess water from your hands to speed up the drying process, although this step is optional. By following these steps, you can effectively and efficiently use a hand dryer machine in public restrooms.

Mainly there are two types of hand dryers, being hands under (HU) dryers and high-speed hands under (HSHU) dryers, which is the first one has an older technology and therefore consumes more energy when used, while the HSHU are those with a higher air jet speed, which allows drying hands in a shorter time, most of the machines of this type are of the Dyson brand and they are the ones that have made more studies about their products. [22,35]

LCA of AHDM

As such, the level of drying becomes the same in both machines, only the usage time in the HU is longer (15-20 seconds) while the HSHU has a shorter duration (10-14 seconds). This is due to the fact that the air outlet velocity of the HSHU is higher but the temperature of the HSHU is lower, which improves the efficiency of the machine. [20,24]

Both drying machines have very similar energy expenditure and GHG emissions, except only at the time of use of the machine where they change drastically.

The HU have an approximate emission of 12.3 g CO₂ eq, per hand drying. They break down as follows, the use of the machine as such makes up the majority of the use with 11.6 g CO₂ eq per use, therefore the remaining CO₂ eq emissions are made up of the manufacturing (0.2 g CO₂ eq) and the materials used (0.5 g CO₂ eq), thus assuming that neither the end of life has GHG emissions and approximating zero transport (only having to be transported once to the destination, unlike paper which has to be constantly replenished). [18,36]

However, HSHUs have a lower GHG emission due to improved technologies in recent years, so their emission is between 3.8 and 8 g CO₂ eq. The difference is due to the analysis carried out by different studies, as the analyses carried out by Dyson show lower emission values than other institutions such as MIT which show higher values. It can be understood that Dyson wants to give a value as low as possible to attract customers, while MIT may not have all the parameters to evaluate the complete LCA, and therefore the difference in the values. [18,22]

The emission from the use at the time of hand drying is therefore around 7.3 g CO₂ eq, if one chooses to analyse the worst case option (from the HSHU model), so both the emissions when manufacturing, material production, end of life and transport are the same in both models (HU and HSHU).

The CED of the HU shows that there is a total energy consumption of 298 KJ eq of energy at the end of life of the product, while the HSHU has a consumption of 140 KJ eq. At the time of use for hand drying the HU uses 281 KJ eq and the HSHU 121 KJ eq of energy, assuming that both have the same end of life (with zero associated energy expenditure) and with equal transport and manufacturing, being these 2 KJ eq and 1 KJ eq respectively, their minimum difference apart from the use is in the materials which have 14 KJ eq and 16 KJ eq of energy expenditure for the HU and HSHU respectively. [23]

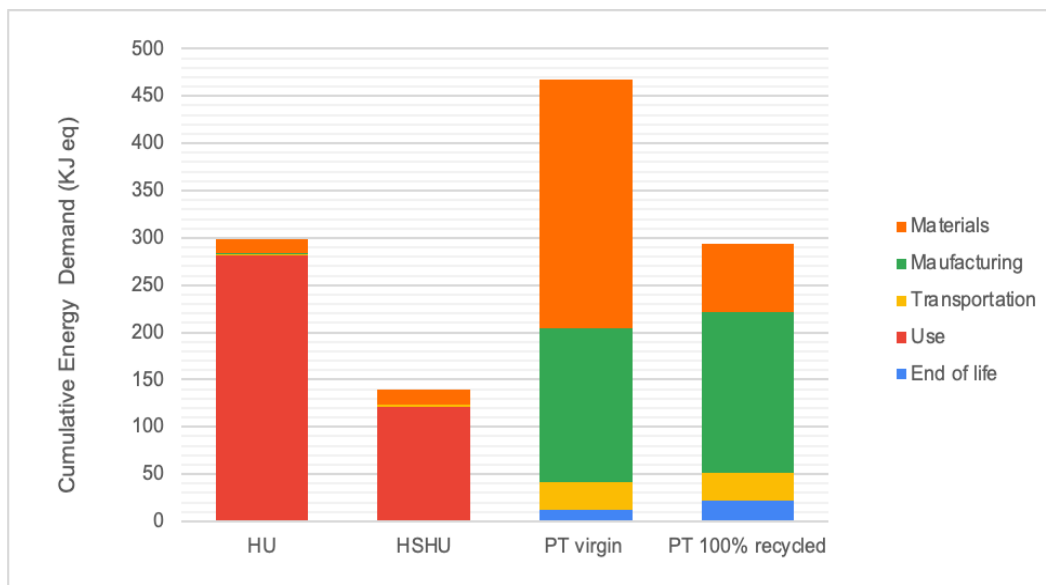


Figure 2. Cumulative energy comparison in the lifecycle of paper towels and hand air drying machines

So by evaluating the LCAs of each type of drying, it is clear which of the two drying methods is more environmentally damaging and more energy costly. Knowing therefore that virgin paper towels are the most unfavorable option in both aspects. Followed by HU and 100% recycled PT as shown in the Figure 2.

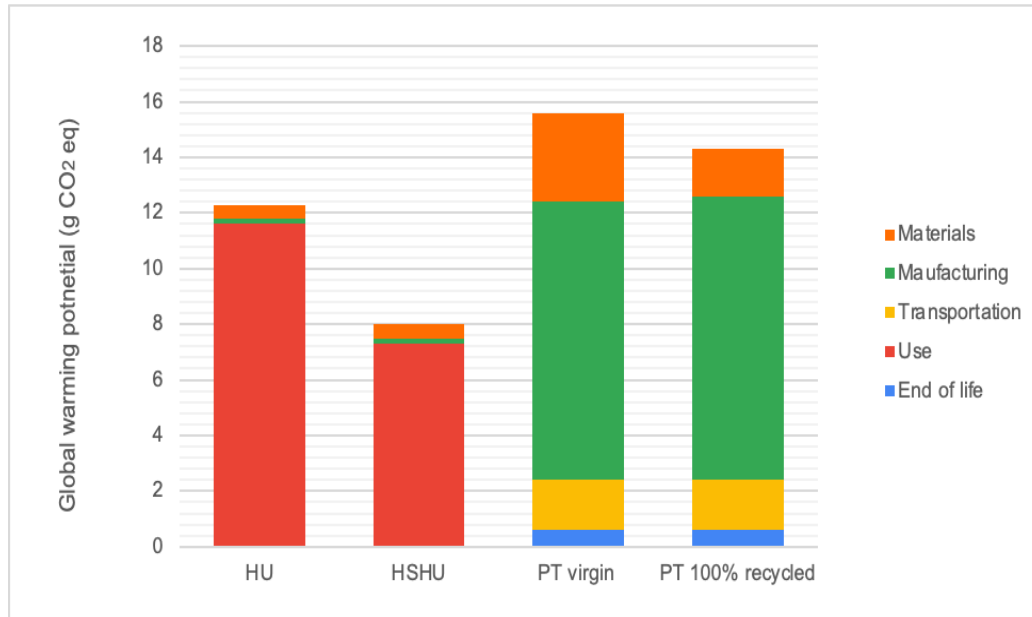


Figure 3. Emissions of greenhouse gasses in all of the lifecycle of paper towels and hand air drying machines

Figure 3 shows visually how there is a trend again when it comes to environmental pollution, as paper towels are the most polluting, regardless of whether they are recycled or not. It can be seen how there is a relationship with both graphs where the biggest consumer of energy and environmental pollution is the virgin PT, and the smallest consumer and polluter is the HSHU.

3.1.4 Overall

This section provides a comprehensive analysis of the outcomes derived from the Life Cycle Assessment (LCA) conducted to compare two prevalent hand drying methods: paper towels and high-speed Air Hand Drying Machines (HSHU). The analysis focuses on quantifiable metrics, including carbon emissions per hand drying operation, cumulative energy demand (CED), and waste generation at the end of the lifecycle, to evaluate the environmental impact of each method.

Virgin paper towels were identified as the least environmentally friendly option, displaying the highest carbon emissions at approximately 15.6 grams of carbon dioxide equivalent (g CO₂ eq) per hand drying operation. This elevated carbon footprint can be attributed to the energy-intensive manufacturing process and the utilization of non-recycled materials. The cumulative energy demand associated with virgin paper towels was notably high, reaching 467 kilojoules equivalent (KJ eq). Predominantly, the manufacturing phase accounted for the majority of energy consumption. At the end of their lifecycle, virgin paper towels contributed significantly to waste generation, resulting in 47.1 kilograms of waste. Disposing of this waste presents notable environmental challenges, primarily concerning landfill disposal.

Although 100% recycled paper towels displayed a slightly lower carbon footprint, emitting around 14.8 g CO₂ eq per hand drying operation, they still exhibited a considerable environmental impact. The CED associated with 100% recycled paper towels was reduced compared to their virgin counterparts, totaling 295 KJ eq. Nonetheless, the manufacturing phase remained a prominent contributor to overall energy consumption. Similar to virgin paper towels, 100% recycled paper towels generated a substantial 47.2 kilograms of waste at the conclusion of their lifecycle.

Hand Air Drying Machines, in particular HSHU, demonstrated a notable reduction in carbon emissions, emitting approximately 7.3 g CO₂ eq per hand drying operation. This reduction can be attributed to advancements in technology and enhanced energy efficiency. HSHU machines exhibited significantly lower cumulative energy demand, with an approximate value of 140 KJ eq, underscoring their energy-efficient nature.

As a whole, this analysis unequivocally establishes HSHU machines as the most environmentally responsible option for hand drying. They substantially reduce carbon emissions, energy consumption per hand drying operation, and waste generation. In contrast, both virgin and 100% recycled paper towels, while offering convenience, impose a higher environmental burden.

These findings hold substantial implications for sustainability and environmental stewardship. Opting for HSHU machines for hand drying in public facilities aligns with objectives aimed at reducing greenhouse gas emissions and promoting ecologically sound practices, as espoused by initiatives like 'The European Green Pact.'

3.2 Collected survey data - Demographic profiles

In this section we proceed to analyze the results obtained in the survey with the intention of clarifying the second objective (To evaluate the public's awareness regarding the environmental impact of both methods and to determine their willingness to adapt their routines for reducing energy consumption in favor of a more environmentally friendly option).

To this end, the data obtained in the survey is presented compared demographically by the three demographic questions and also showing an overall assessment of the opinion of the sample population surveyed.

The surveyed population consisted of 171 people from the city of Valencia, who answered the 3 demographic questions and the 12 questions to find out how informed they are and what their tastes, preferences and beliefs are about hand drying with PT and AHDM. This number of surveyed people is above the target that had been set on 95% confidence level +/- 8% accuracy, therefore the survey complies to the confidence levels given.

Table 2. Distribution by level of education of the data obtained in the survey

Highest diploma	Survey respondents	Percentage respondents
Primary education or below	4	2.3%
Secondary education	13	7.6%
Highschool or equivalent	19	11.1%
Medium-grade vocational training	9	5.3%
Professional training of a superior level	16	9.4%
University degree	84	49.1%
Master's degree or higher	26	15.2%

Firstly, the evaluation was conducted based on the participants' level of education, considering their highest diploma obtained. As shown in Table 2, all education levels are represented in the survey responses. However, there is a notable overrepresentation of individuals with university degrees, which may not entirely reflect the actual population distribution in Valencia. Nonetheless, the participation rates in the other education categories appear to align more closely with the expected percentage corresponding to the population of Valencia.[37]

Table 3. Distribution by age generation of the data obtained in the survey

Generation	Time criteria	Survey respondents	Percentage respondents
Silent Generation	Born between 1926 and 1945	0	0%
Baby Boomers	Born between 1946 and 1964	7	4.1%
Generation X	Born between 1965 and 1980	81	47.4%
Generation Y	Born between 1981 and 2000	51	29.8%
Generation Z	Born from 2001 onwards	32	18.7%

As depicted in Table 3, the survey's participation from generations with limited technology access or less familiarity with its usage, such as the 'Silent Generation' and 'Baby Boomers,' has been minimal or non-existent, therefore it has been decided not to include them in the graphics as they would appear as a blank column. This limitation was anticipated before the survey was conducted. The 'Silent Generation,' being the oldest group, had no representation in the survey. On the other hand, the 'Baby Boomers,' the second oldest generation, had a participation rate of only 4.1%, with merely 7 respondents.

Table 4. Distribution by type of living environment of the data obtained in the survey

Type of living environment	Survey respondents	Percentage respondents
Urban	121	70.8%
Suburban	27	15.8%
Rural	23	13.5%

Finally, the third variable aims to compare the type of living environment. As shown in Table 4, it becomes evident that the vast majority of the population lives in an urban environment (70.8%). This finding aligns closely with the expected result for the urban population, which was anticipated to be around 72%, indicating the accuracy of the survey's depiction of the population. Additionally, the expected suburban percentage was 12%, and the survey results

revealed a respondent percentage of 15.5%, further providing valuable insights into the distribution of living environments among the surveyed population. [38]

3.3 Analysis of survey respondents' opinion

3.3.1 Use of drying methods

The survey begins with the intention of assessing respondents' most common use of hand drying methods. The first three questions are asked to see if there is a preference when it comes to drying.

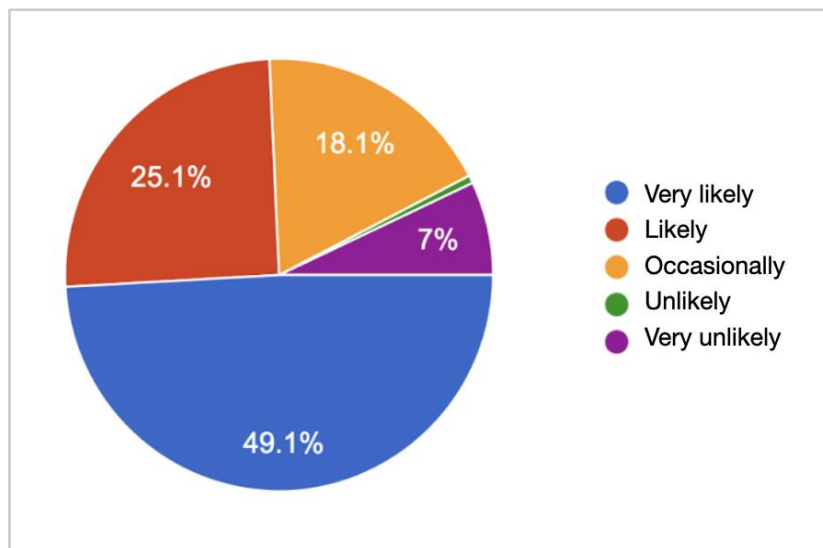


Figure 4. Use of paper towels in public restrooms for drying hands

When assessing drying preference, Figure 4 shows that the majority of people are "Likely" (25.1%) or "Very likely" (49.1%) to use PTs to dry their hands, making up 74.2% of the surveyed population. While 18.1% only "Occasionally" and the remaining 7.7% choose to rate as "Unlikely" or "Very unlikely".

When checking the three demographic questions, there is no clear pattern that could indicate any trend (App. 2, App. 3, App. 4).

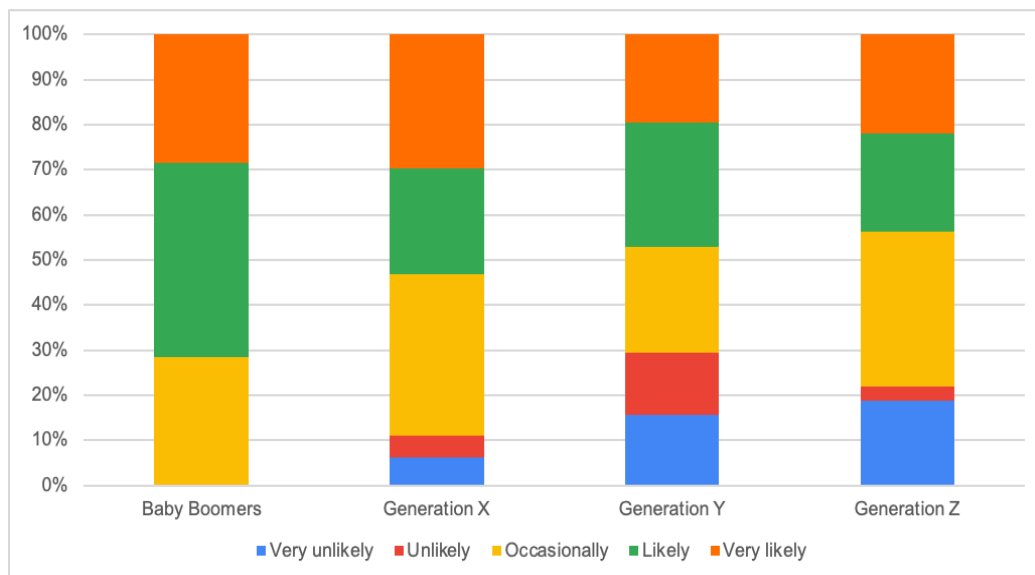


Figure 5. Use of air machines for hand drying in public toilets by age group

However, it can be seen that the use of HADM does show a generational demographic pattern as can be seen in Figure 5, as it appears to show that the older the respondent the more likely they are to use HADM. The overall data shows that 50.2% of the population is "Likely" or "Very likely" to use this type of drying, with each option accounting for 25.2%, while "Occasionally" accounts for 31.6% with this option being the most popular.

Thus, 20.9% of Generation Z respondents are "Likely" and "Very likely" to use a hand dryer, making 41.8% of this generation opt for this type of drying. While "Very unlikely" is 17.5% and "Unlikely" is 3.8% for this same generation, compared to older generations such as the Baby Boomers, none of the respondents show "Unlikely" or "Very unlikely" usage.

As shown in Figure b, the growth of HADM use increases with increasing age, which is contrary to what was initially believed that older generations are more reluctant to new hand drying trends and technologies, and surprising on the other hand how younger generations are initially more attached to the use of PTs.

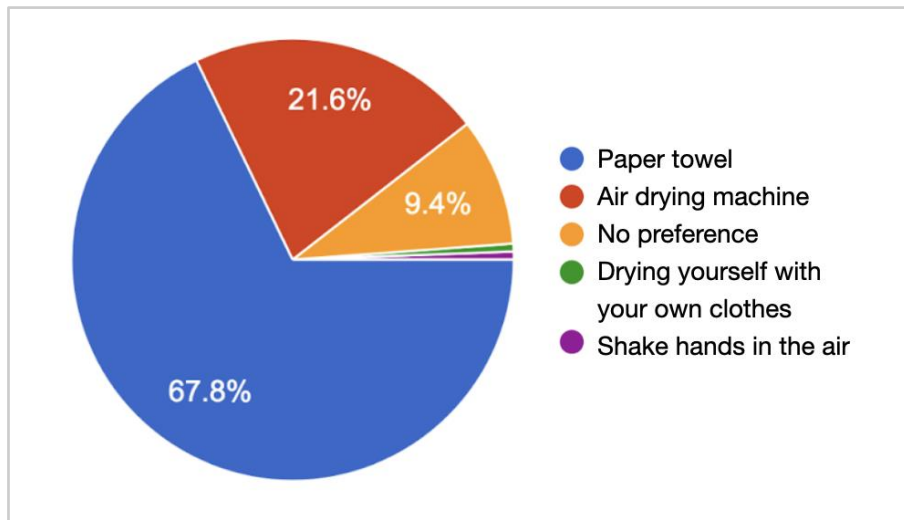


Figure 6. Preference for hand drying in public toilets

Regardless of age, education or place of residence, PTs are the preferred hand drying option with 67.8% of respondents opting for this option. Only 21.6% prefer HADM over PT, while the remaining percentage have no preference and 2% show two different opinions to highlight as alternative measures. "Drying yourself with our own clothes" and "Shake hands in the air" are the respondents' proposals, although impractical but effective in reducing energy use and environmental costs.

Therefore, there is a clear preference for the type of hand drying. This can be directly related to Figure 6 which indicates the level of satisfaction with using each method.

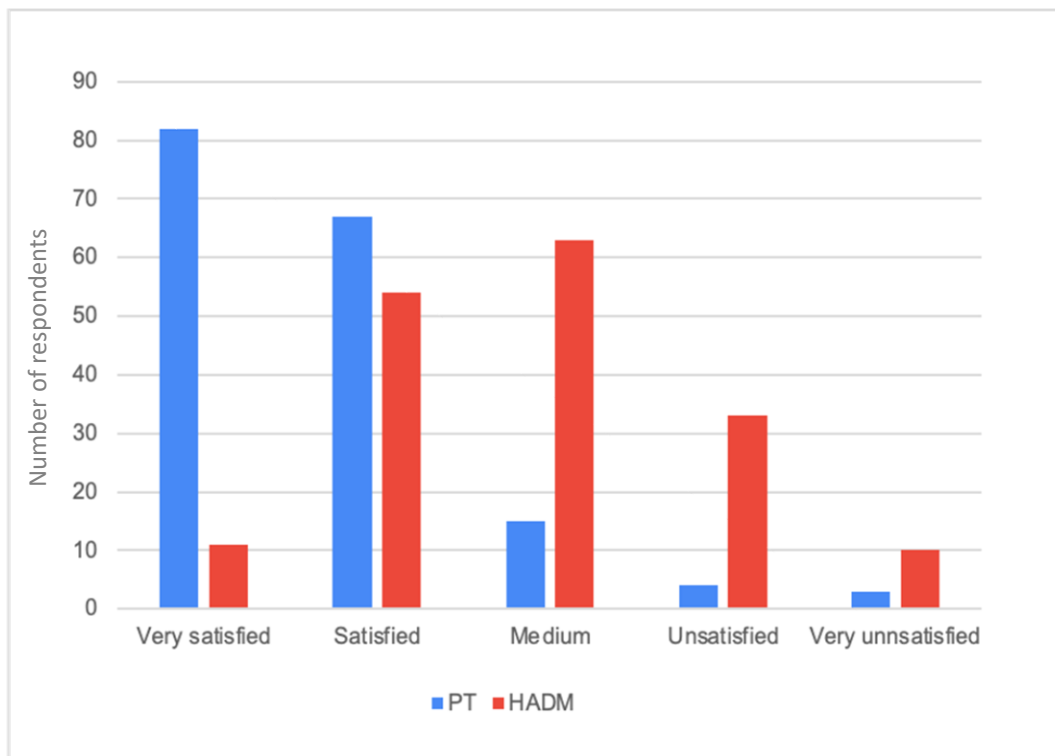


Figure 7. Relationship between satisfaction with hand drying by respondents comparing paper towels with air dryers.

Considering the overall results, paper towels seem to have a "Satisfied" (39.2%) and "Very satisfied" (48%) result for the majority of the population as these responses make up 87.2% of the respondents, seeing a clear result as only 4.1% of the total are "Unsatisfied" or "Very unsatisfied".

However, the result is not the same for the HADMs as the satisfaction levels of the population are much lower than for the previous method. Figure 7 shows that in this case the population has a tendency towards the center, with 36.8% opting for "Medium" (the most voted option), while only 6.4% are "Very satisfied" and 5.8% "Very unsatisfied". Therefore, the remaining percentage is divided into "Satisfied" with 31.6% and "Unsatisfied" with 19.3%.

Therefore, there is a relationship between the level of use and the level of user satisfaction, which is important to take into account in order to evaluate whether, even if it is clear which method the population prefers, a change of habits for energy and environmental improvement can be considered.

3.3.2. Knowledge and willingness to change habits

In order to correctly evaluate the second objective of the thesis, it was proposed to understand the willingness of the users to change their habits, as well as their knowledge of the contamination of both methods (PT and HADM). For this purpose, several questions

were asked to assess whether once they knew that HADMs are less polluting they would be willing to change their use.

In first place, the population was asked "I am willing to change the way I dry my hands" in order to see at first if people are reluctant to change or if on the other hand there could be an initial willingness to do so. Therefore, for this first question the respondents are not asked which is the less polluting option, since at this moment the intention is to evaluate in which initial position the respondents are and to evaluate their predisposition to change and their willingness to learn more about the subject from this question.

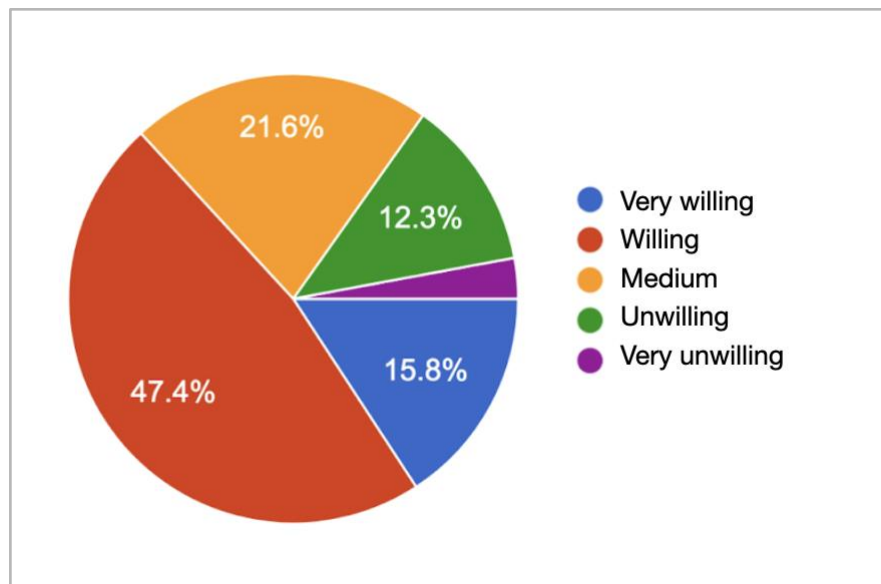


Figure 8. Respondents' willingness to change drying method

The survey shows that 47.4% of the respondents are "Willing" and 15.8% "Very willing" to change the hand drying method as can be seen in Figure 8, while 21.6% remain at "Medium". On the other hand, 2.9% and 12.3% form the respondents who are "Very unwilling" and "Unwilling" to change, therefore in principle this group should remain unchanged once the information about the most polluting method is introduced to the population. While those who have opted for the "Medium" option are those who might change their mind in the future. Assuming that the majority of respondents continue to prefer paper towels to HADMs.

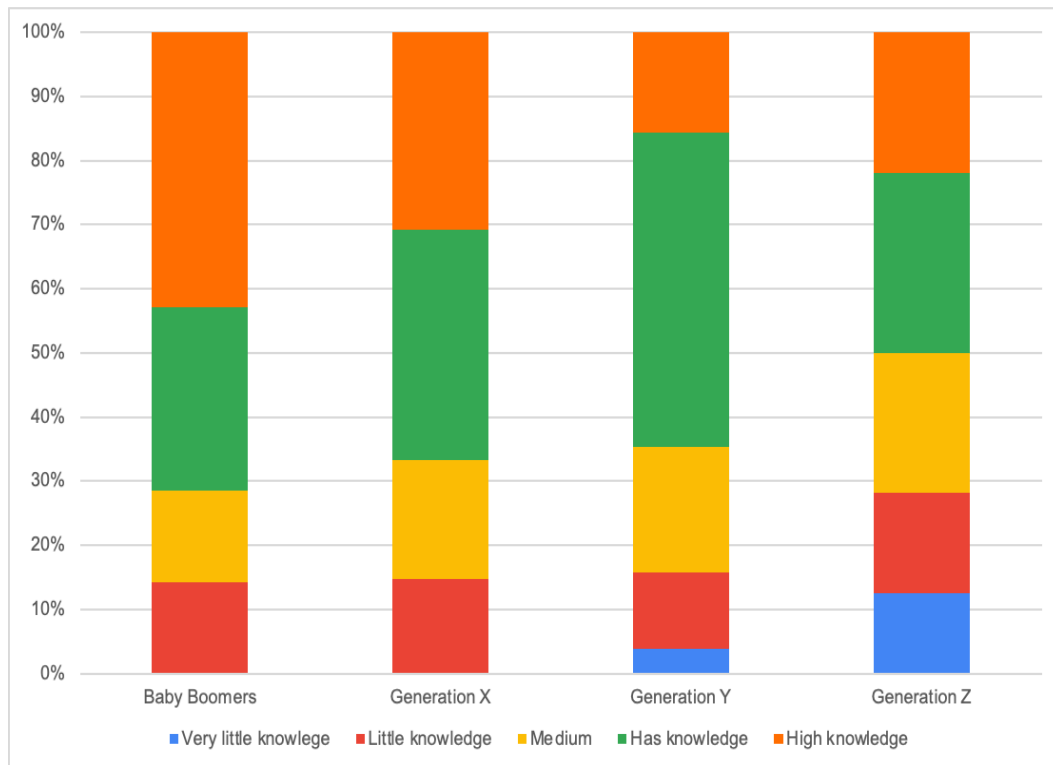


Figure 9. Opinion of the population on whether they think they are aware of the environmental impact caused by paper towels classified by age

In general terms, 38% of the surveyed population considers that they have "Has knowledge" about the environmental impact of PTs and 25.1% consider themselves to have "High knowledge". This question is influenced by the demographic question of age, as it can be clearly seen in Figure 9 that as age increases, so does knowledge of environmental issues. Only the two youngest generations 'Generation Y' and 'Generation Z' consider that they have "Very little knowledge" on the subject, obtaining 3.4% and 12.2% respectively. Where the level of knowledge on the subject also increases as one gets older, having only 50% "High knowledge" and "Knowledge" in 'Generation Z', which increases progressively in each generation up to the 'Baby Boomers' who have 71.8% "High knowledge" and "Knowledge".

As age increases, people become more knowledgeable about more technical topics, such as in this case environmental impact. It could be believed at first that there could be the same pattern with the level of studies, however there is no correlation showing this result.

Once this information is obtained, we ask again if there is willingness to change, but this time introducing to the respondent the information of which method is the most detrimental.

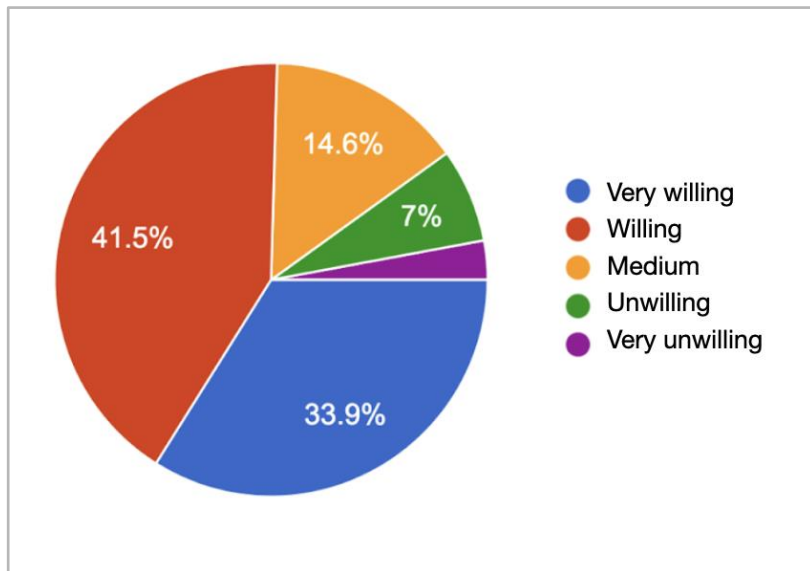


Figure 10. Willingness to switch to air machine knowing that paper towels pollute more.

Knowing the most polluting option and asking for the most eco-friendly option, 33.9% now opt for "Very willing" and 41.5% for "Willing" as shown in Figure 10. So now 75.4% of respondents are willing to change the way they dry their hands in a public restroom, compared to the previous result where 63.2% of the population was somewhat willing to change.

Taking into account that by providing the population with information on the most polluting process, the willingness to change has increased by 12.2%, thus evaluating one of the sub-objectives.

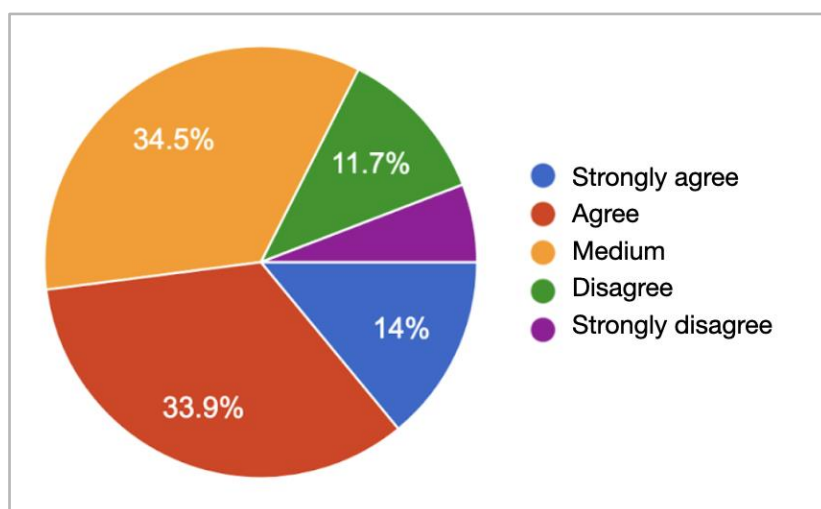


Figure 11. Belief that a big impact when saving energy will be used by air machines.

However, as Figure 11 shows, only 33.9% "Agree" that switching to HADM would have a major impact on reducing energy expenditure, and 14% "Strongly agree". Giving a slight connotation of regression to the 'regression to the mean' phenomenon since the majority of the population has opted for the "Medium" option (34.5%).

Finally, it is evaluated whether the respondents want to obtain more information on the subject, and to be able to check again if there is a willingness to change.

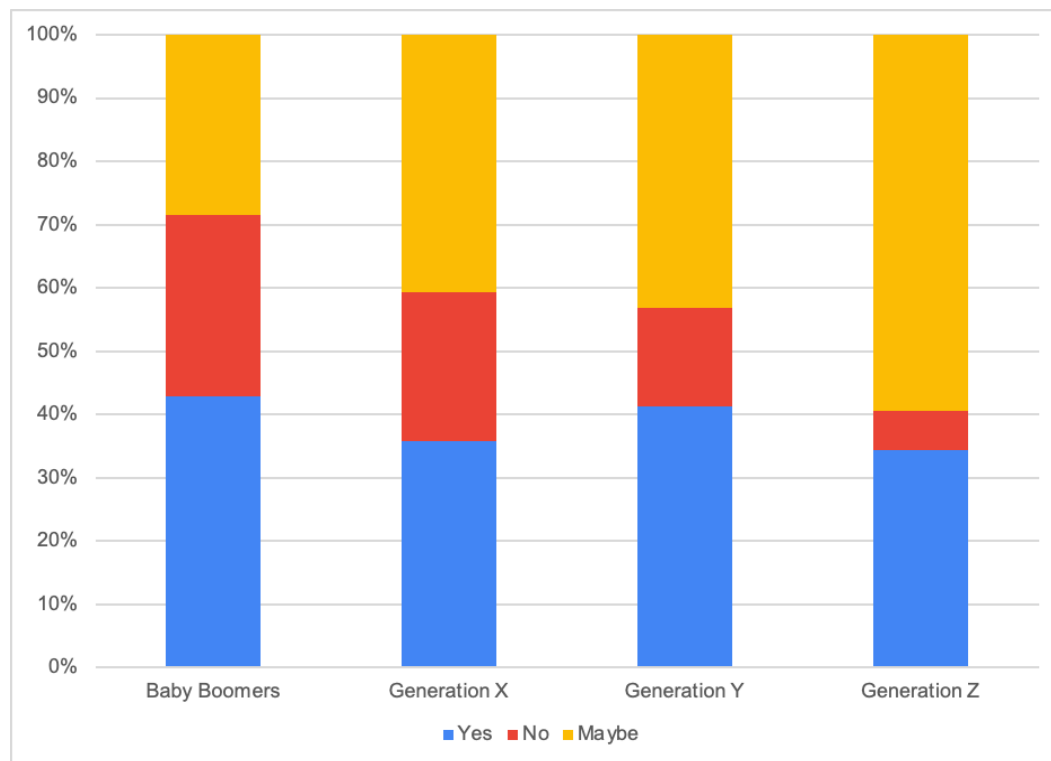


Figure 12. Do respondents want to be more informed about the topic

Contrary to what we were seeing previously where older generations thought they were more knowledgeable about the topic, Figure 12 clearly shows how as age increases, they are clearer about whether or not they want to know more. While the percentage of the population that voted "Yes" remains constant across all generations at around 37.4%, as age advances it goes from 5.1% "No" in 'Generation Z' to 28.3% in the 'Baby Boomers' generation.

3.3.3. Profile of surveyed

It has been decided to look in depth at 4 of the surveyed questions to see what profile of respondent is likely to opt for each of the answer options of the question. The questions evaluated are 3, 8, 10 and 11 (Appendix A.a), which have been chosen because they are those that can provide us with the most information at the level of analysis and the objectives of this work. All the questions are analyzed showing a complete profile of the respondent by means of the different demographic questions and presented in the tables below.

The voter profile for any question has consisted of finding the person who is most likely to choose the most answered option. Therefore, both the answer that is most likely to be selected (in green), with the profile of the person who would respond to it, as well as the profiles of the people who are most likely to answer the other answer options, are shown in the tables below. In view of these evaluations, responses to demographic questions such as 'Silent Generation' have been discarded and no response has been obtained from this generation in the survey.

Table 5. Table showing the most voted questions to question 3, showing the percentage of voters for that demographic question

	Educational Level		Generation		Place of residence	
Paper Towel	Highschool	73.4%	Generation Y	73.4%	Urban	71.9%
Air machine	Professional training of a superior level	28.5%	Generation X	28.3%	Rural	30.4%

According to the data, the PTs are the preference in every demographic question which gives us the profile as shown in green in Table 5, that a person that is most likely to dry their hands with paper towels will live in an urban environment, be from the Generation Y and has a highschool diploma at most. Table 5 clearly shows how air machines have a completely different profile of users, as there they are rural, from Generation X and have a professional training of a superior level at most.

It is curious to see how at first it had been thought that the profile of HADM use might not be rural, since in theory they have more deeply rooted traditions, but it can be seen that 30.4% of the respondents who live in a rural environment opt for this option, being higher than the percentage of respondents in an urban (19.8%) and suburban (24%) environment.

Table 6. Table showing the most voted questions to question 8, showing the percentage of voters for that demographic question

	Educational Level		Generation		Place of residence	
Very unwilling	Master	7.6%	Generation Y	3.9%	Rural	8.6%
Unwilling	Master	19.2%	Baby Boom	42.8%	Suburban	14.8%
Medium	Highschool	30.7%	Generation X	29.6%	Rural	30.4%
Willing	Primary	100.0%	Generation Z	53.1%	Urban	49.5%
Very willing	Highschool + Master	23.0%	Generation Y	21.5%	Suburban	25.9%

As shown in Table 6, the most voted profile for the question "I am willing to change the way I dry my hands" is the one in which the person is "Willing" to change his/her hand drying habits, being the most common that this person has a primary education, since 100% of the people who have these studies at most have voted this option. In addition, the profile is completed with 53.1% of people from Generation X opting for this answer and 49.5% of people living in an urban environment.

Table 7. Table showing the most voted questions to question 10, showing the percentage of voters for that demographic question

	Educational Level		Generation		Place of residence	
Very unwilling	Master	7.6%	Generation Y	3.9%	Rural	4.3%
Unwilling	Master	11.5%	Baby Boom	14.2%	Urban	8.2%%
Medium	Highschool	31.5%	Baby Boom	28.5%	Rural	17.3%
Willing	Highschool	46.1%	Generation Z	46.8%	Suburban	44.4%
Very willing	Medium-grade vocational training	44.4%	Generation X	39.5%	Rural	39.1%

The profile for the most answered answer for this question consists in a person with a highschool diploma, from Generation Z living in a suburban environment, which answered “Willing” when knowing that the PTs contaminate more that the HADMs. It is again followed closely by the profile of “Very Willing” however, they do not resemble in any demographic response.

It is important to mention that looking at the profiles of the answers in Table 7, as the level of education gets higher, the willingness to change habits reduces, as for the profile of the answers for “Unwilling” and “Very Unwilling” have a both a profile of a person with a Master’s degree, constituting 7.6% and 11.5% of the percentage of this demographic group.

Table 8. Table showing the most voted questions to question 11, showing the percentage of voters for that demographic question

	Educational Level		Generation		Place of residence	
Strongly disagree	Master	11.5%	Baby Boom	14.2%	Suburban	7.4%
Disagree	University degree	15.4%	Generation Z	18.7%	Urban	13.2%
Medium	Medium-grade vocational training	55.5%	Baby Boom	42.8%	Suburban	44.4%
Agree	Highschool	47.3%	Generation Z	37.5%	Rural	39.1%
Strongly agree	Professional training of a superior level	18.7%	Generation X	16.0%	Urban	14.8%

In Table 8 we can see how the previously mentioned 'Regression to the Mean' phenomenon reappears and so here we can get a clearer answer as to what is happening. The most likely answer option is "Medium" being more likely to be voted by Baby Boomers, who live in a suburban environment and have a medium-grade vocational training.

It again shows how the closest response options to 'Medium' (55.5%, 42.8% and 44.4%), which are 'Agree' and 'Disagree', are those with the most votes in their response profile below, while those with the fewest votes are those furthest away from the medium response (11.5%, 14.2% and 7.4%).

4 Discussion

After collecting data informing about the difference in the life cycle of the paper towels and the hands air drying machines, where it could be then used to perform a survey consulting citizens regarding their willingness and knowledge about the current situation of the differences energetically and environmentally speaking. Some main aspects have been identified and are exposed below.

- The energy consumption is usually bigger for the PT than for the HADM, taking into account the total energy consumption in the lifecycle of the entire process, from the moment raw materials are obtained to the end of life of the product.

It can be assured by the data obtained from the LCA comparisons, that regardless of the origin of the paper towels, whether they are recycled (regardless of the percentage recycled), the expenditure due mostly to the manufacture of the product and its transport far exceeds the energy used in the air drying machines.

While HADMs, regardless of whether they are HU or HSHU, have a lower energy consumption over their lifetime, as HU consumes 298 KJ eq and HSHU 140 KJ eq. Comparing them with the energy consumption values of 295 KJ eq and 467 KJ eq of 100% recycled and virgin paper towels respectively, it can be seen that virgin paper towels clearly stand out, being almost twice as much as the second type of drying.

However, the HU and the 100% virgin paper towels have a similar energy consumption, so it can be intuited that the low efficiency of these types of hand air dryers, having to see that this is the oldest system and with higher consumption, in this case there would be the same energy consumption.

On the other hand, the improvements in the technologies show how clearly the HSHU has a lower energy use throughout its life, being the moment in which it consumes more at the time of its use, as well as the HU. In this case the HSHU has a technological improvement and energy consumption is reduced compared to the HU by 160 KJ eq. This value is higher than the energy consumption of the HSHU (121 KJ eq).

In conclusion, taking into account that HADMs improved significantly year after year (being the most frequently installed in public restrooms), and that this makes their energy consumption related to their useful life lower, in case of being able to dry hands with HADMs, regardless of the type of model they are, it is very likely that they are better in terms of energy consumption than PTs.

- Regardless of the material used to manufacture the paper towel, HADMs will be a better choice in environmental terms.

The data that has been collected shows that regardless of the pulping process of the material, both PT models will produce a greater amount of g CO₂ eq over their lifetime than either HADM model.

In addition to this data, it should also be included in the analysis that paper towels are products that cannot be recycled (as they contain organic material) and are often disposed of in landfills, and that TP's must be maintained to be clean and constantly replenished (using transportation and personnel to keep up with demand), as well as the additional use of boxes that can be used to distribute them or garbage bags that are used to collect them once they have been used.

They produce 47.1 kg (virgin) and 47.2 kg (100% recycled) of waste (only considering paper towels, not any type of packaging) throughout their life cycle.

However, HADMs can be recycled at the end of their useful life and the moment of greatest pollution is at the time of use of the product, which could be reduced if the energy used for the use would come from renewable sources, thus reducing the environmental impact.

In conclusion, with an emission of between 14.3 - 15.6 g CO₂ eq per use of the TP, and an emission of between 8 - 12.3 g CO₂ eq of the HADM (HU and HSHU respectively). The conclusion is clear that PTs are more environmentally polluting than HADMs.

Moreover, it should also be taken into account that these values are calculated taking into account that only a pair of PT is taken to dry the hands, it is very common to dispense more than necessary to dry our hands by accident or to obtain a better result. So, the numbers could be greater and so this is a limitation that must be taken into account. As such, there are other implications as it is estimated that 1 ton of virgin paper towels can consume 17 trees, which pollutes 7,000 gallons of water. [25,34]

Focusing the perspectives from a more sustainable point of view, one could evaluate where the energy comes from or analyze the origin of the energy, as for example the energy from the MIT that only comes from fossil fuels. [18] With a comparison at the country level, as this would provide an energy background of the country and would show the renewable or non-renewable origin of the energy used in the useful life of the hand dryer. Therefore, taking into account that the HADM make the most impact on their use, if the energy is greener, this will mean that the impact of CO₂ on the environment will be much less. Due to this, countries where fossil fuels can be the main source of producing electricity will have a much greater negative impact on the environment than those countries with more energy renewable production.

With respect to the LCAs obtained above for the PT and HADM processes, in both cases limitations that have elapsed in the work have been taken into account. The information on LCA is limited and few sources with reliable data (peer review papers or government articles) report in detail the emissions or consumption of the processes. Therefore, although

the results are clear and it is believed that a legitimate and accurate analysis of LCAs has been obtained, it is difficult to know exactly how accurate the information is.

Other points identified from this work that should be commented on are as follows.

- The population believes that they are aware of the environmental impact caused by the two hand drying processes and in turn are mostly willing to try to change their habits in order to improve energy consumption and environmental impact.

With the results obtained in the survey, it is shown that although the people surveyed have a clear preference for hand drying with PT (67.8% of the overall population), since they believe that they obtain a better result with this drying technique, it is shown how, knowing that this process is more harmful to the environment, there is a willingness to change to air dryers.

The willingness to change was assessed by two questions. The first one evaluated whether the surveyed population would be willing to change their habits, at this time the preferences of the population were known and it was known that the majority preferred the most polluting use (PT) and only one for the 21.6% HADM, therefore it is assumed that the majority of the population would opt for the PT.

63.2% of the respondents are willing to change the way they dry their hands at first, without any other incentive. This already shows a very positive predisposition to change, since 21.6% also opted for the neutral option, which could change their opinion when they knew that they could improve their energy and environmental performance by switching. Mentioning that looking at the profiles, as the level of education gets higher, the willingness to change habits reduces, as for the profile of the answers for "Unwilling" and "Very Unwilling" constituting 7.6% and 11.5% of the people with a Master degree.

When asked if they would switch to HADMs as an environmental and energy improvement option, 75.4% are now willing to change the way they dry their hands in a public toilet.

This clearly shows how people seem to be aware of the need to help contribute to energy reduction and thus to the 2050 targets of the European plan. They themselves consider themselves to be aware of the impact of drying methods, with 63.1% saying they are aware of the issue.

Although they are willing and claim to be aware of the issue, the majority opt for a neutral option when answering the question "I think it would have a big impact in terms of saving energy if I air-dry". This may indicate a slight connotation of regression to the 'regression to the mean' phenomenon since the majority of the population opted for the "Medium" option (34.5%), it is proven by the profile of the surveyed in that particular question where the percentages of profile according to each answer decrease when being the furthest from this answer. The phenomenon

of regression to the mean indicates that when respondents are not clear about their opinion, for various reasons such as lack of knowledge, ambiguity of the question or indifference on the subject, so when evaluating this response, the data may not be entirely accurate due to the high number of responses to the neutral opposition.

Therefore, with the data obtained from the survey, it is believed that the population does want to participate in the change so that there is a lower energy consumption and an environmental improvement. Although it is questioned the knowledge that the population says they have on the subject and what may suggest the answer to other questions related to more detail on this.

- The last point to note is that it seems that there have not been very significant relationships in relation to the demographic parameters presented (education, generation and place of residence), except in the generation relationship where generational patterns have been observed in some questions.

With respect to education and place of residence, no significant results were obtained in which a pattern appears (see Appendix A.b. and Appendix A.d.). It did not matter in the case of education whether they have a higher level of education or not, there was no clear relationship, one might think that the level of education and the age of the sampled population could have similar results, but it has been observed that there is no pattern in the levels of education.

The same has happened with the place of residence, which at first was thought to have a greater tendency for respondents living in rural areas not to want to change to HADM, but it has turned out to be a demographic parameter that does not show changes.

Moreover regarding the profile answers it is seen that there is no apparent correlation between the age or the living environment regarding the questions evaluated. However it does seem to have a correlation with the educational level, as in question 8 and question 10, when assessing the willingness to change the habits of drying the hands, people with higher education are the profile of “Unwilling” or “Very unwilling” answers. The same tendency in the profiles repeats again as it seems that although they are told that PT are worse, they do not change their opinions.

Another parameter that shows trends in some of the questions is the generational parameter. It can be observed in questions that indicate that they may have greater knowledge of the environmental and energy issues since.

Only the two youngest generations 'Generation Y' and 'Generation Z' consider that they have "Very little knowledge" on the subject, obtaining 3.4% and 12.2% respectively. Where the level of knowledge on the subject also increases as they get older, having only 50% of "High knowledge" and "Knowledge" in 'Generation Z',

which increases progressively in each generation until the 'Baby Boomers' who have 71.8% of "High knowledge" and "Knowledge".

In conclusion, it is considered that the demographic questions, even though at the beginning it could be understood that they could be related to the survey, it has been shown that only one of the parameters, the age of the surveyed population, can be grouped to make a more detailed analysis.

The survey reveals that paper towels are the preferred choice for hand drying in public restrooms among most respondents, especially those in urban areas and from Generation Y or older. However, younger generations and individuals with lower education levels show greater willingness to consider alternative hand drying methods, particularly when they are made aware of the environmental impact of paper towels.

While a significant percentage of respondents express a willingness to change their hand drying habits, there is a need for further education regarding the environmental benefits of alternative methods, such as hand dryers. Additionally, some skepticism exists about the energy-saving potential of hand dryers. Overall, this data highlights the potential for a shift towards more sustainable hand drying practices with targeted awareness campaigns and environmental education.

Difficulties appeared when evaluating the profile of the questions as it was tedious to relate every question. It would have been desirable to have demographic parameters that could be more affected by the survey, although it has been possible to make an incorrect general analysis of the overall population sampled and to draw significant conclusions.

5 Conclusions

5.1 Study results

In alignment with the predefined research aims, this study conducted a thorough examination of two prevalent methods of hand drying in public settings: paper towels and air hand drying machines (HADMs). The primary objectives were to assess the environmental impact and energy consumption associated with these methods and to assess public awareness of these environmental consequences and willingness to embrace more sustainable alternatives.

The first objective "To analyze and compare the energy consumption and environmental impact of paper towels and air hand drying machines throughout their lifecycle, from their raw materials to their disposal" has been answered in the way proposed using scientific papers to collect the data provided from the LCA.

The key results in the papers have shown that paper towels are clearly the most harmful to the environment, not only are they the most harmful option, but regardless of the material with which they are made, they are clearly the ones that stand out above HADM. In contrast to paper towels, the HU and HSHU models manage to reduce environmental expenditure by up to half as much as virgin PTs.

The relationship with energy is very similar to the environmental one, since the highest consumption process is for virgin TP and the lowest consumption is for HSHU. In this case, the HU and the 100% recycled TP have a similar final consumption value, although it stands out that the paper towels consume most of the energy when they are manufactured while the air machines consume it at the moment of use of the product.

The second objective has been evaluated by means of a survey of citizens, which has been intended to analyze the objective "To evaluate the public's awareness regarding the environmental impact of both methods and to determine their willingness to adapt their routines for reducing energy consumption in favor of a more environmentally friendly option".

By surveying citizens, we wanted to see what demographic factors might affect their awareness of the issue and whether they influence their willingness to change the way they dry their hands. The results showed that the demographic parameters did show some tendencies with educational parameters showing that with higher education the willingness of changing habits decreases and the generational demographic parameter, where responses were a pattern related to each generation.

It has therefore been found that the adult generations believe that they have a greater knowledge of the more polluting option of hand drying, although this result is not clear, since in later answers there is doubt about the population's knowledge on the subject.

However, it is clear that a large part of the surveyed population, mostly a profile with low studies, is more than willing to change their habits in order to adapt to an improvement in the energy and environmental situation. This seems to indicate that citizens may be aware of the objectives of the European Union's 'Green Plan' for 2050. Both survey methods have had

their limitations when being used, as accurate data is difficult to obtain when calculating the LCA, although it is believed that a true conclusion about the drying processes could be reached, it would have been helpful to find more 'peered' information about the end of life of the drying methods evaluated. Also, the limitations of the survey were not so noticeable since a large number of respondents were reached, but there are some generational groups that are almost absent and could influence the conclusions of the results.

As a final conclusion, this research has elucidated the environmental advantages of HADMs in contrast to paper towels, emphasizing their potential to facilitate progress toward sustainability objectives. Moreover, the survey outcomes indicate a readiness among the public to transition to environmentally friendlier hand drying methods when enlightened about the associated ecological impacts. While some demographic variations were observed, they underscore the necessity for targeted awareness campaigns and educational initiatives aimed at fostering broader adoption of sustainable practices. In conclusion, this study underscores the role of informed choices and behavioral adjustments in addressing environmental challenges and advancing toward the objectives articulated by the European Union for the 2030 agenda.

5.2 Outlook

The study could be continued in several possible ways, since both objectives presented in the paper can be developed to more detailed levels by focusing on different perspectives or details.

First, the first objective analyzes and compares the consumption and environmental effects of different hand drying techniques. The work can be extended by evaluating a larger number of hand drying techniques such as cotton rolls, or by performing a more exhaustive analysis on the differences between each class of air dryers available.

With respect to the evaluation of all the stages of the life of the processes, it is where there have been more complications and where more precise details have been wanted to show, although the study has focused on the objectives, the analysis could be extended to more detailed questions such as the types of GHG emitted. On the other hand, data could also be collected in the laboratory on the use of HADMs or through simulations.

Secondly, to assess people's knowledge and willingness to change, more demographic measures could be assessed that would be relevant to the objective. Further, one could combine the survey method to one in which an older population can more easily participate to obtain relevant data from those generations. Using a statistical software would be beneficial to indicate clearer correlations and more information.

5.3 Perspectives

Regarding further investigations the environmental level, could be investigated which are the areas with the highest risk of having paper towel waste, and how it is transported to the place. In addition, it could be evaluated how the waste affects the surrounding fauna and if it can produce any kind of problem.

A new perspective could be focused on the efficiency of the new technologies that are being developed and that can improve the drying machines, and how these can also improve the quality of hand drying, not only at an energetic level, but also at the level of air cleanliness.

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Appendix A

Appendix A.a. Questions in the survey

Question 1-In public places I use paper towels to dry my hands

Question 2-In public places use hot air machines to dry hands

Question 3-Which method do I prefer for drying hands in public places?

Question 4-How much time do I spend drying my hands with paper towels?

Question 5-How much time do I spend drying my hands with an air machine?

Question 6-I like the result I get with paper towels

Question 7-I like the result I get with the air machines

Question 8-I am willing to change the way I dry my hands

Question 9-I am aware of the environmental impact that paper towels cause

Question 10-Knowing that paper towels contaminate more, I would be willing to change my way of drying my hands to an air machine

Question 11-I think it would have a big impact in terms of saving energy if I air-dry

Question 12-I would like to be more informed on the subject

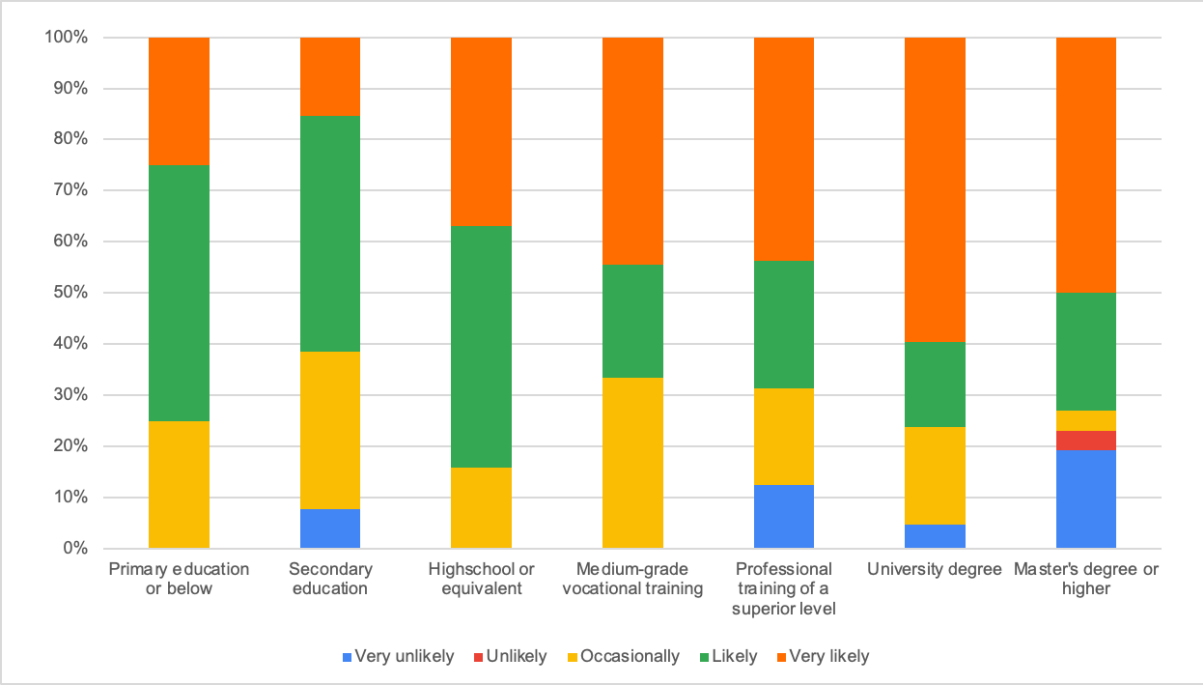
Demographic question 1 (education)-Educational level

Demographic question 2 (generation)-Generation (Year of birth)

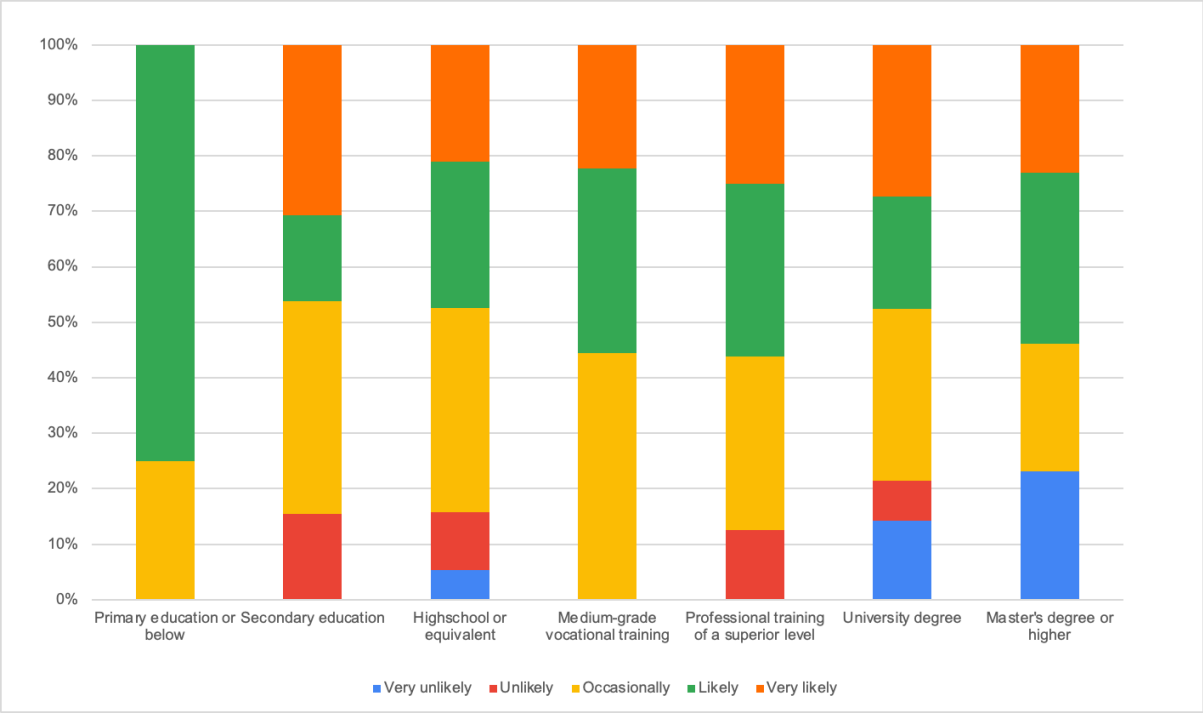
Demographic question 3 (place of residence)- What kind of environment do you currently live in?

Appendix A.b. Demographic question 1 (Education) compared to the questions in the survey

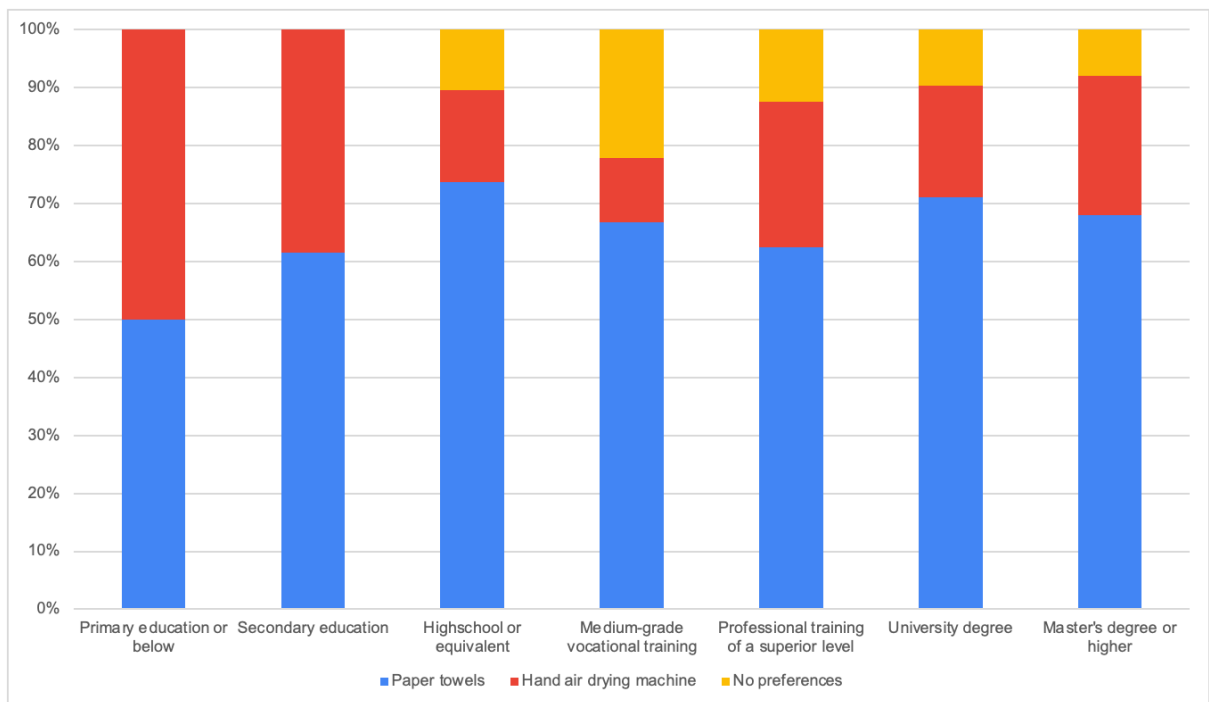
Question 1



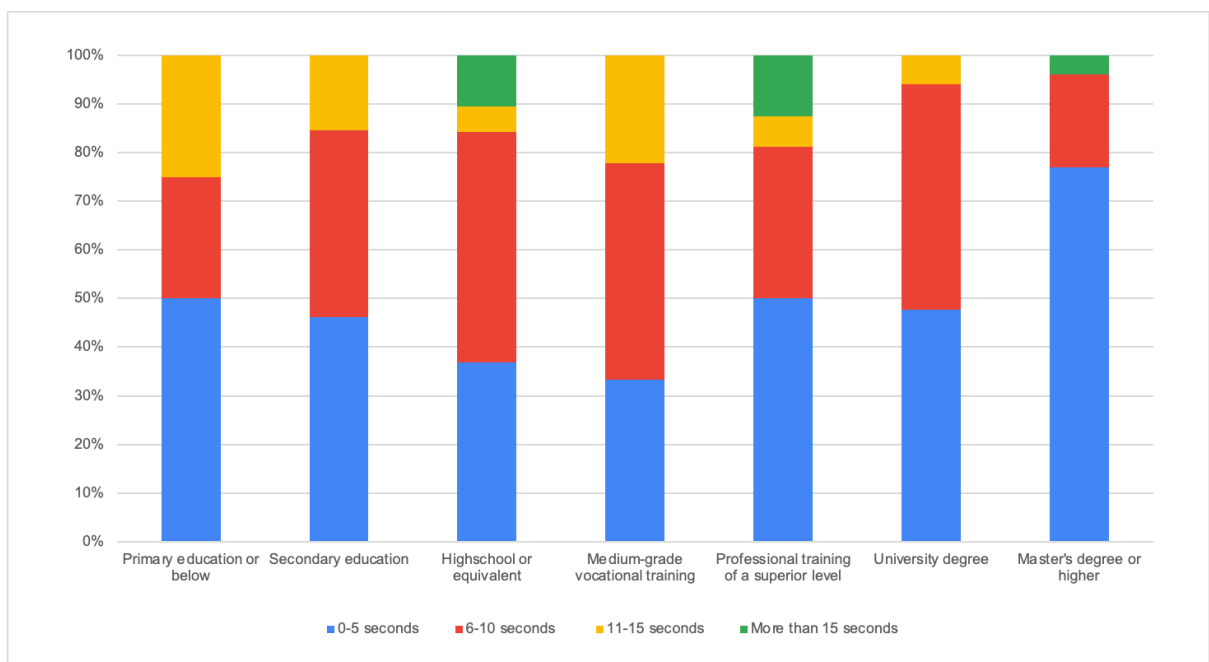
Question 2



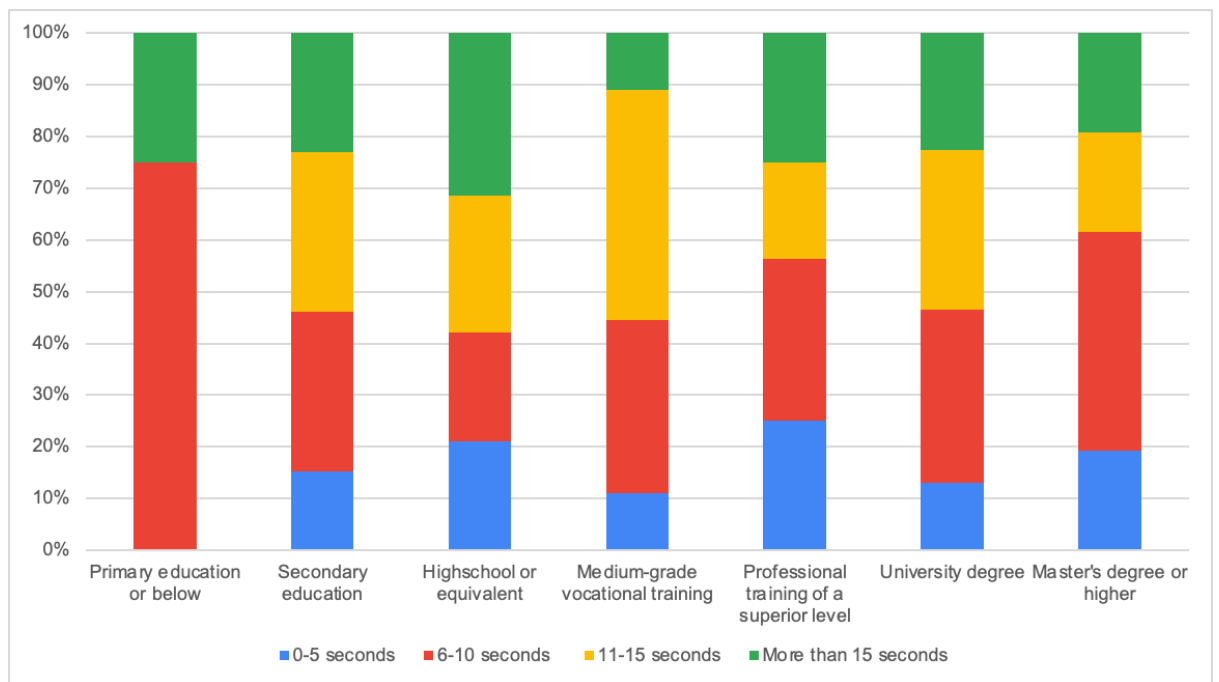
Question 3



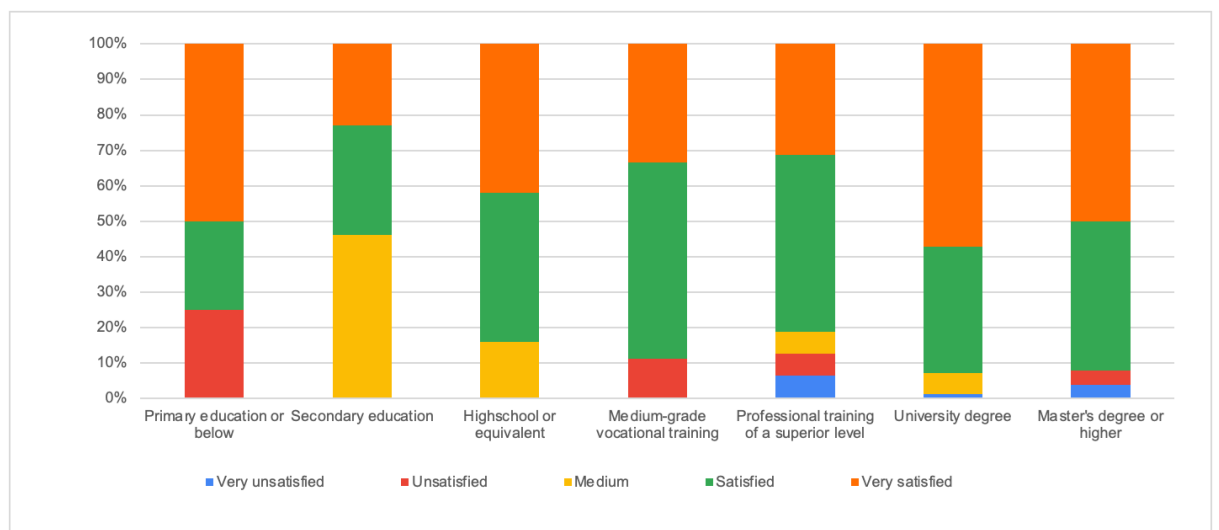
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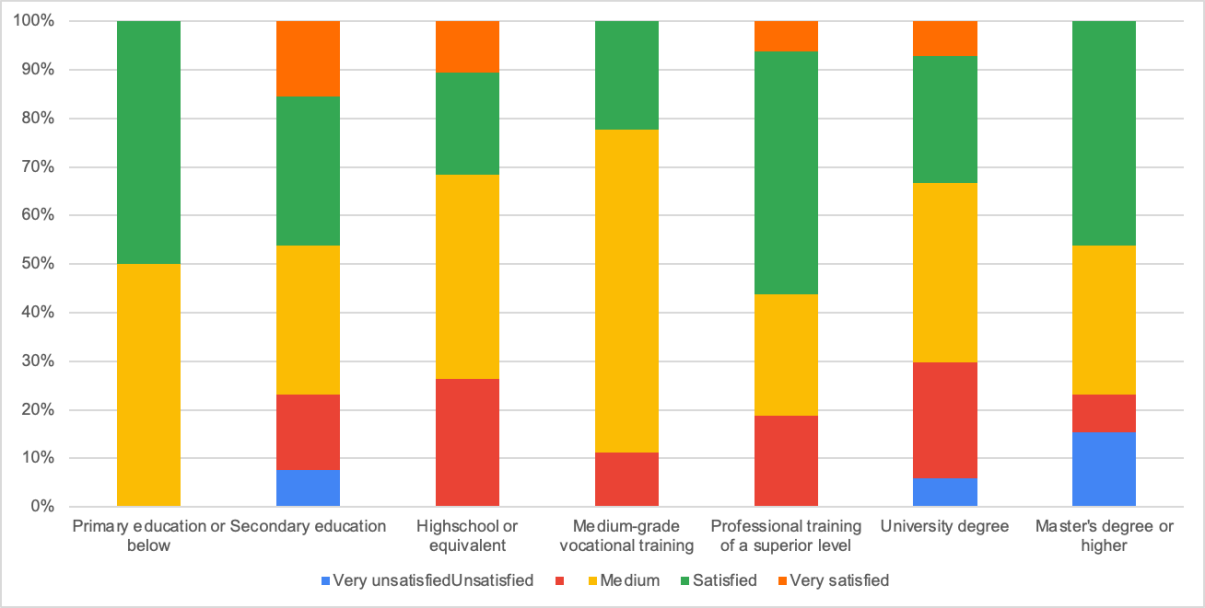
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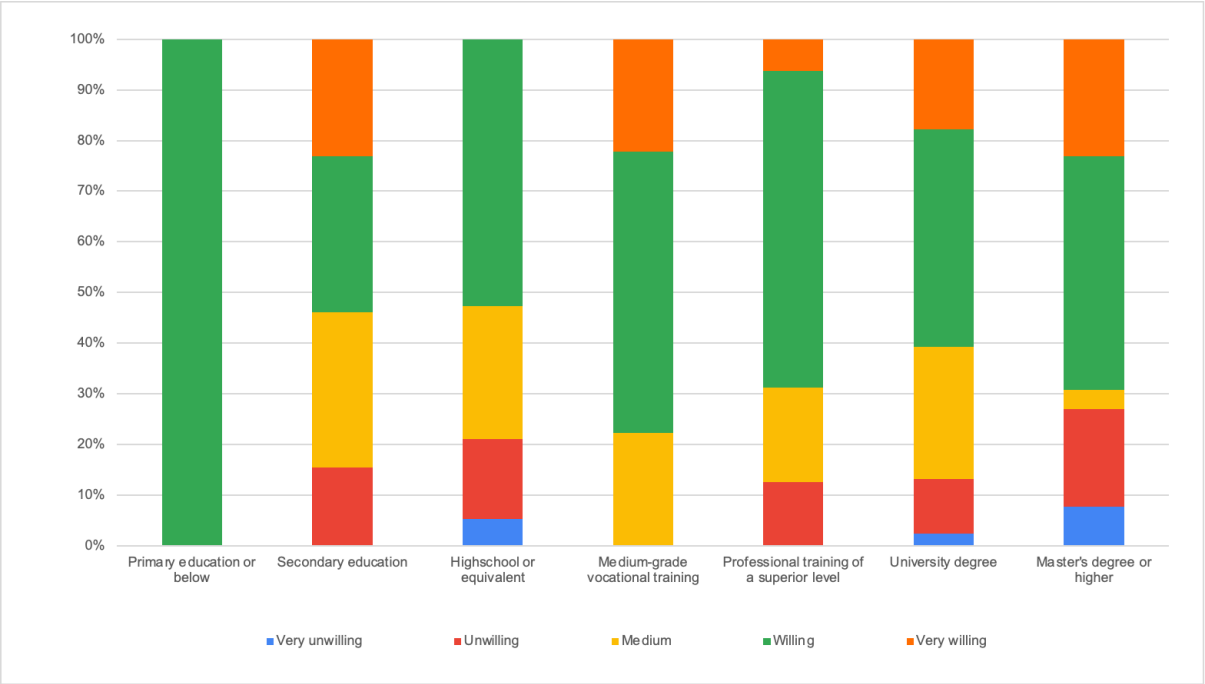
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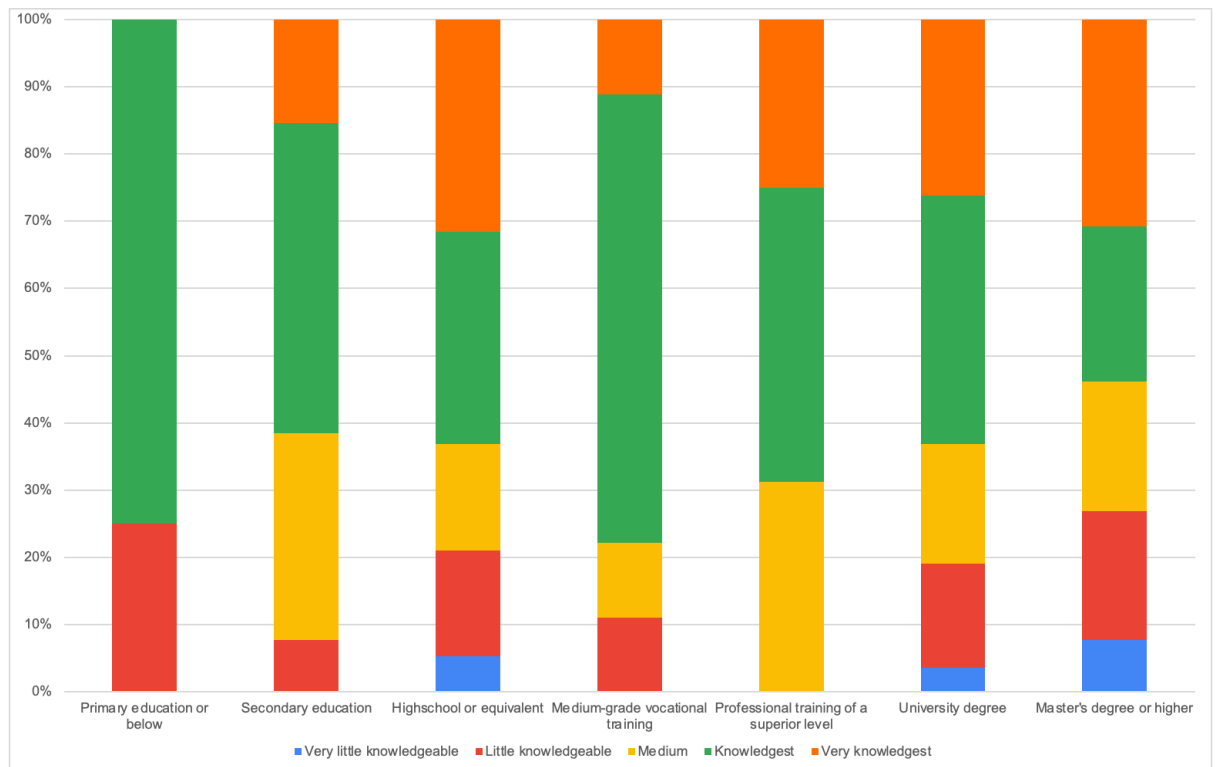
Question 7



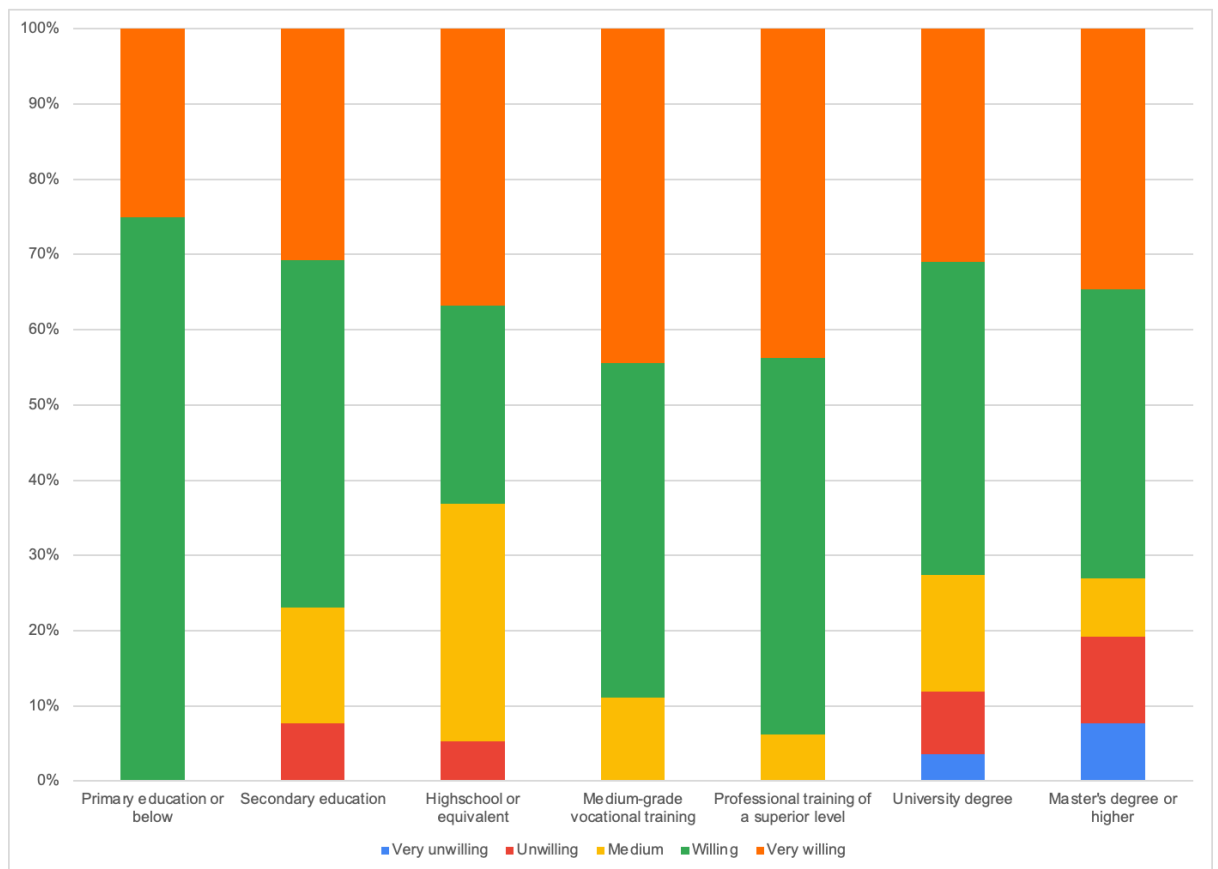
Question 8



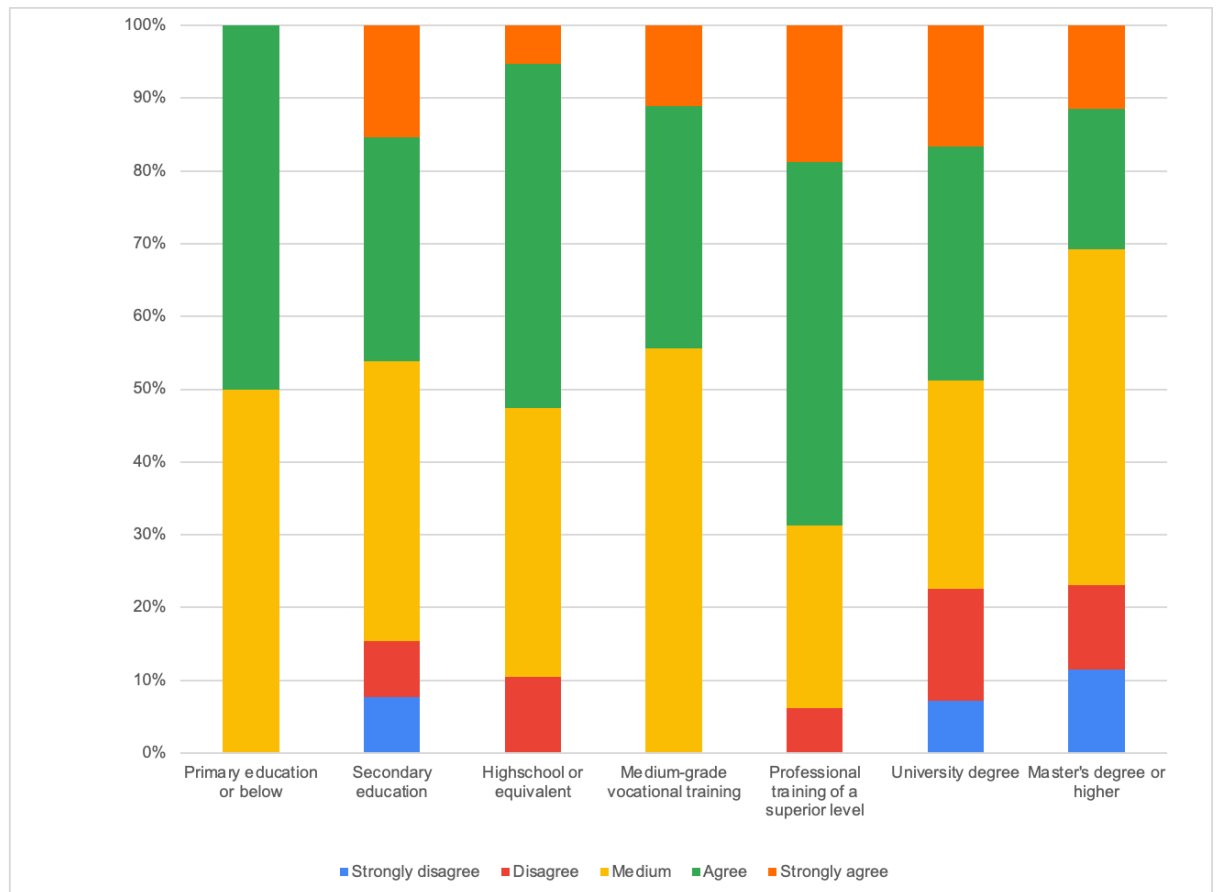
Question 9



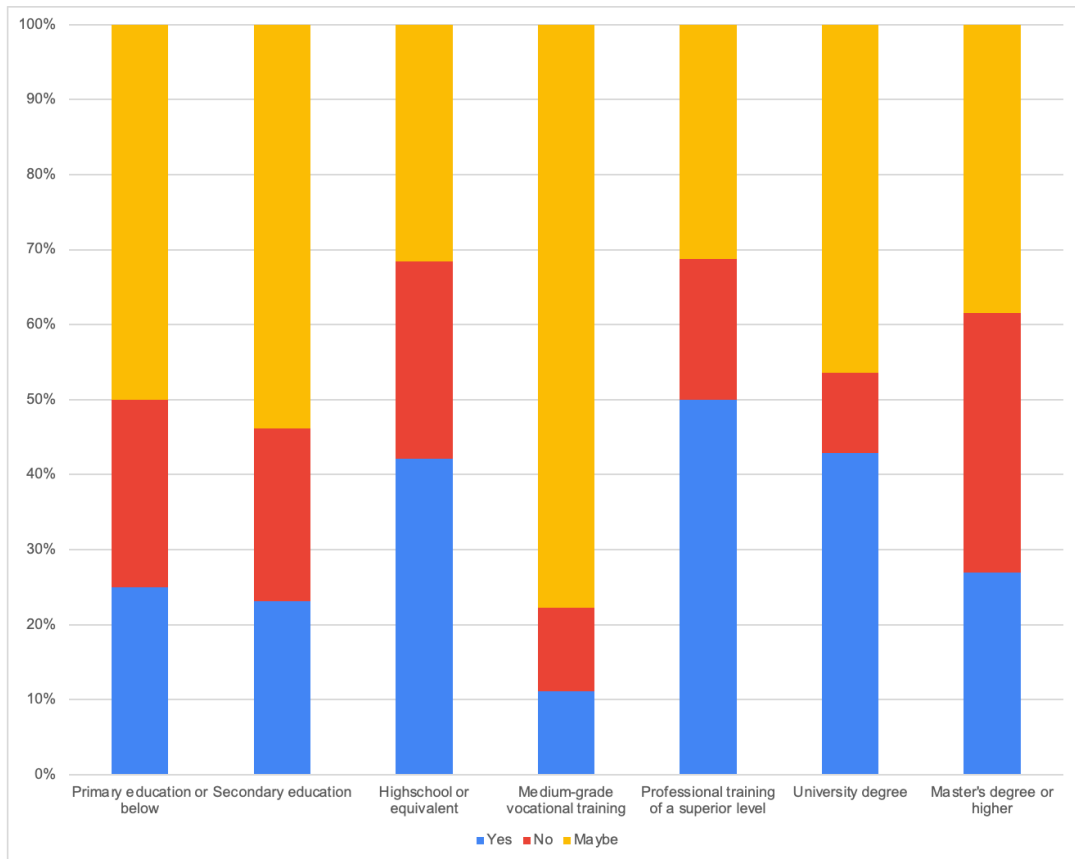
Question 10



Question 11

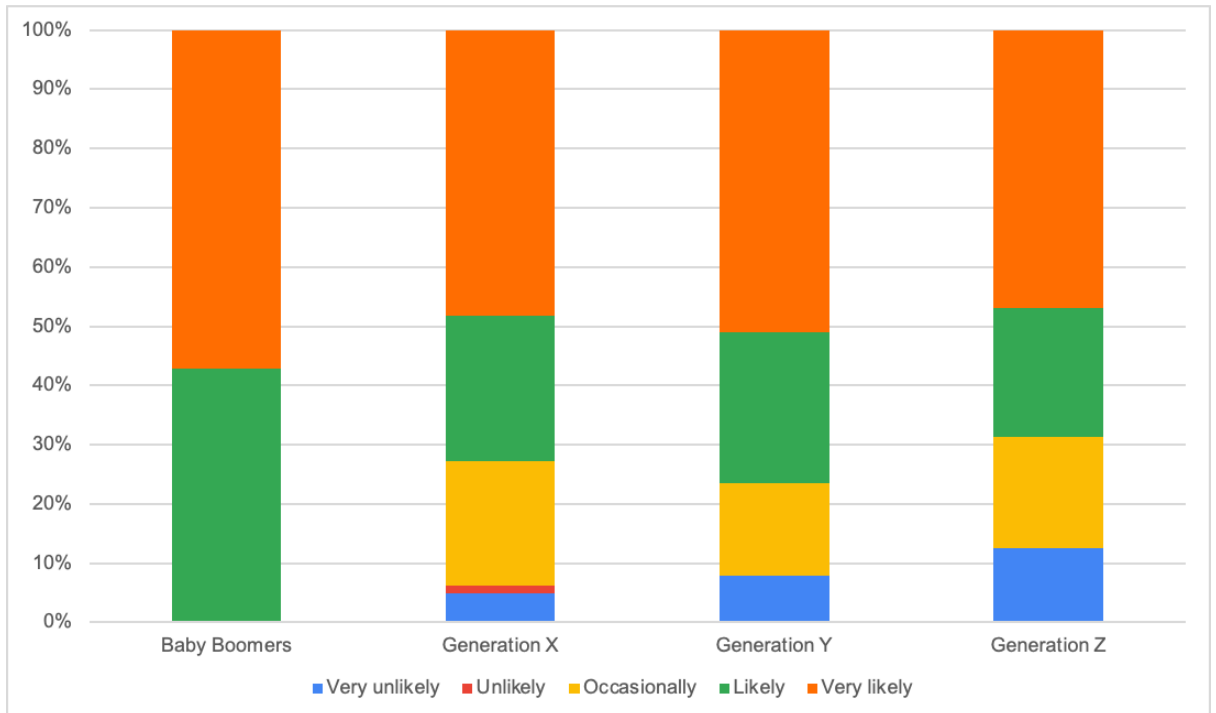


Question 12

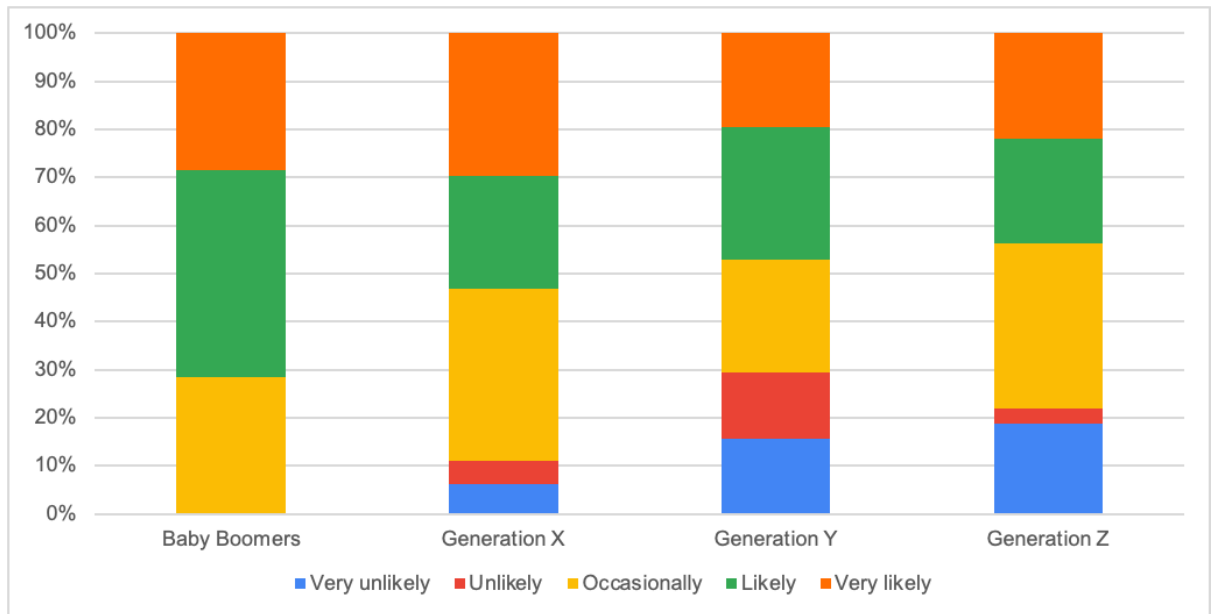


Appendix A.c. Demographic question 2 (Generation) compared to the questions in the survey

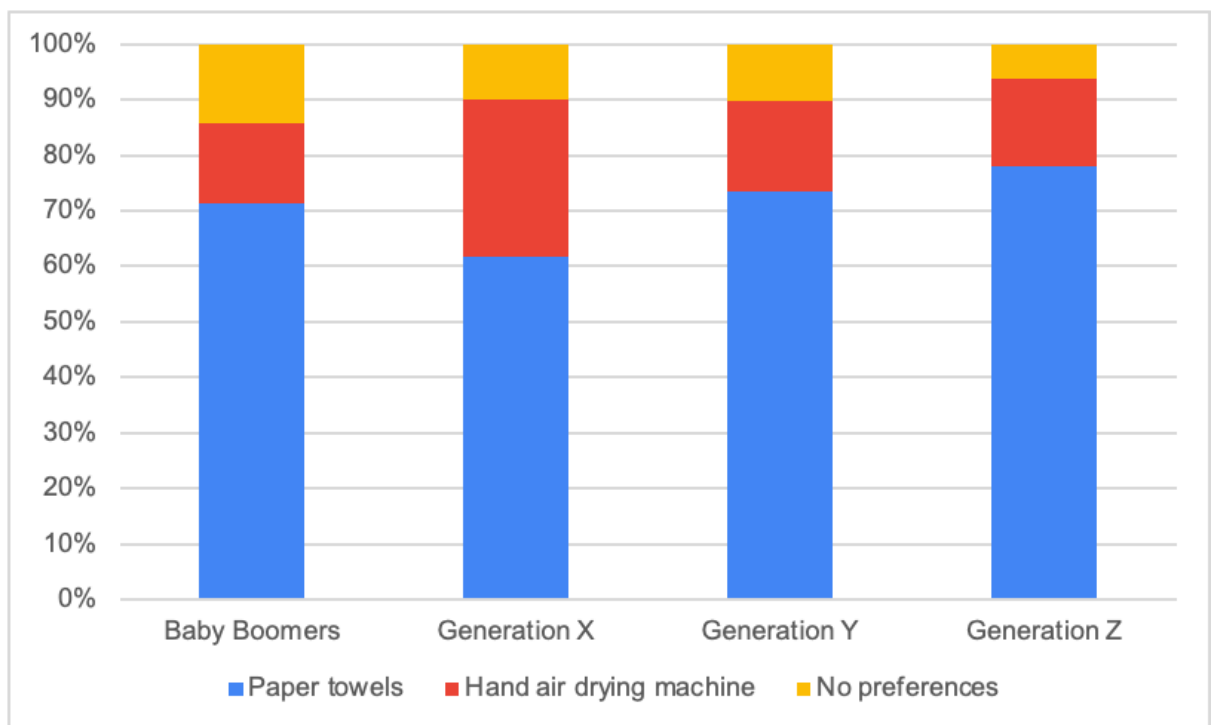
Question 1



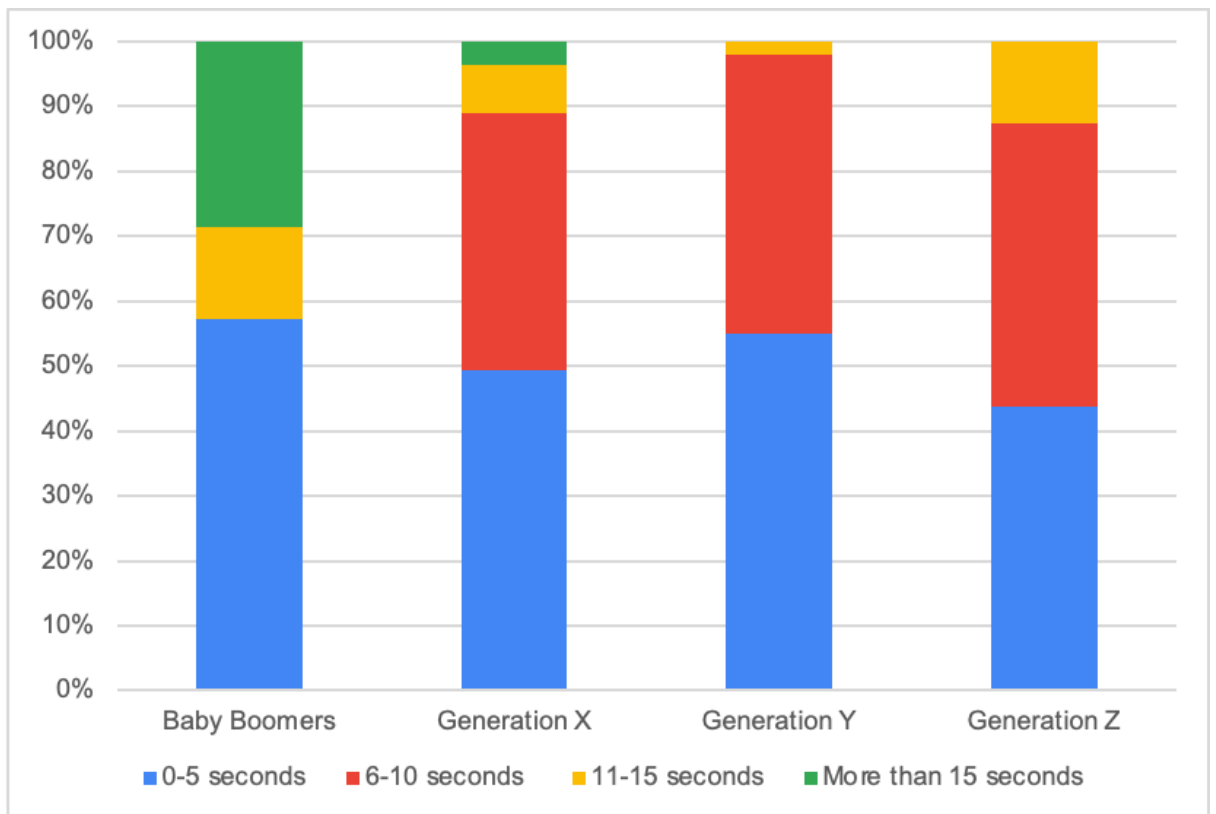
Question 2



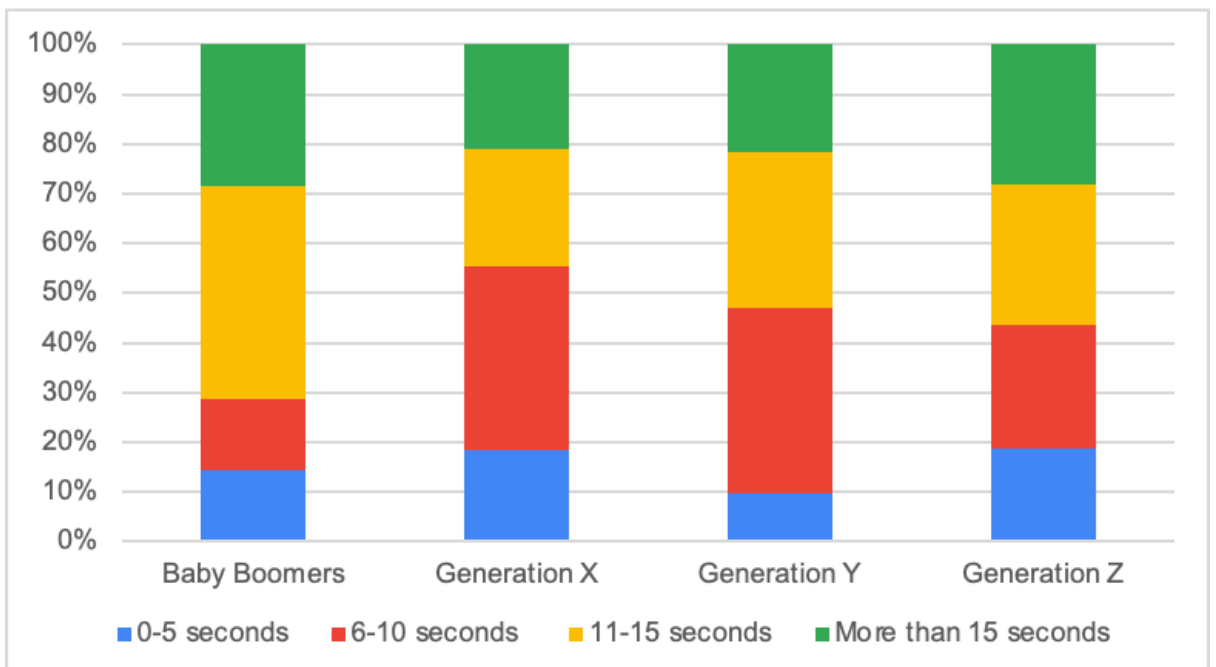
Question 3



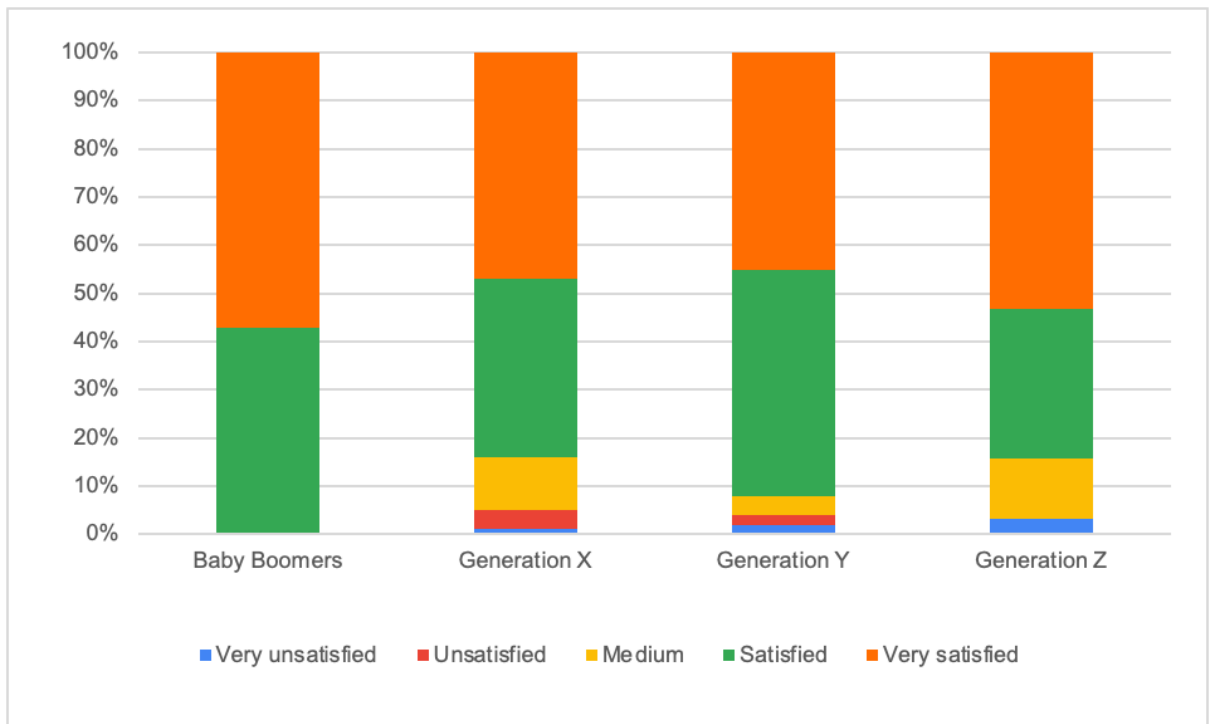
Question 4



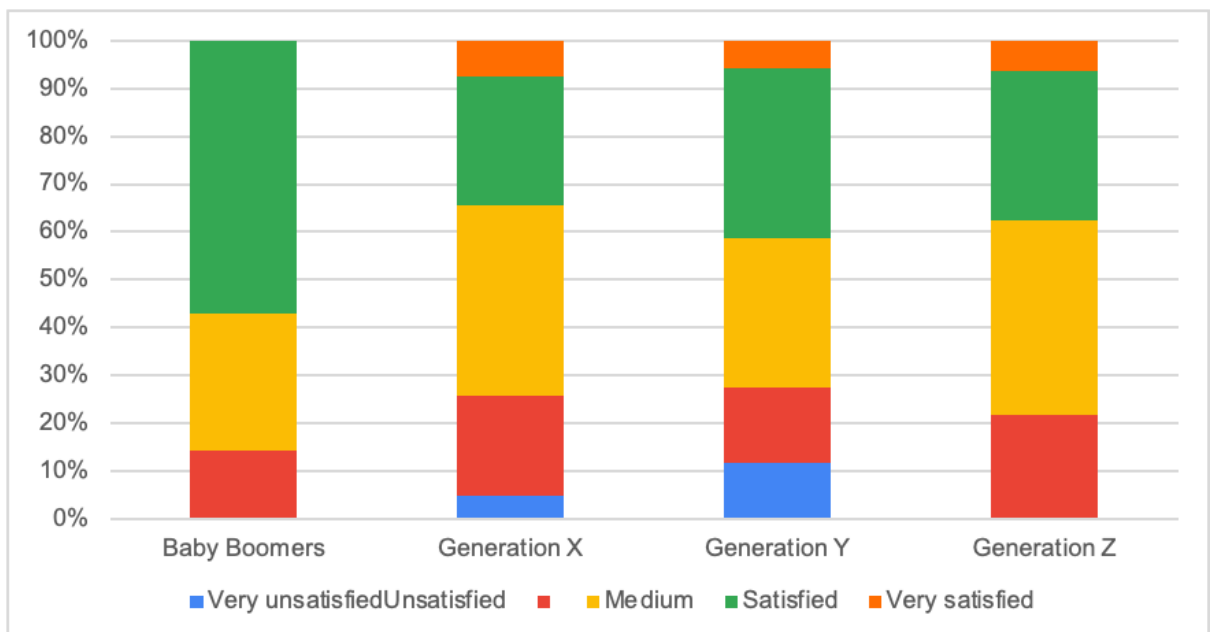
Question 5



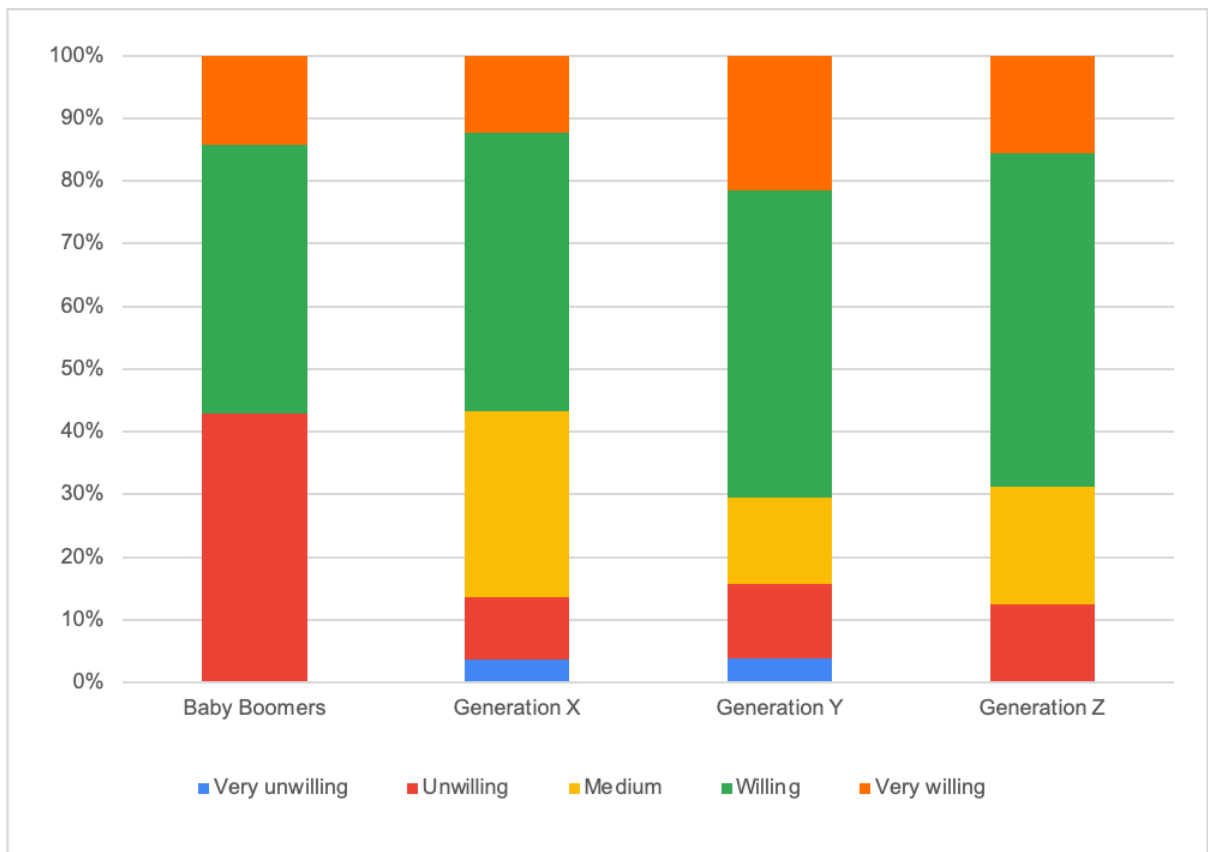
Question 6



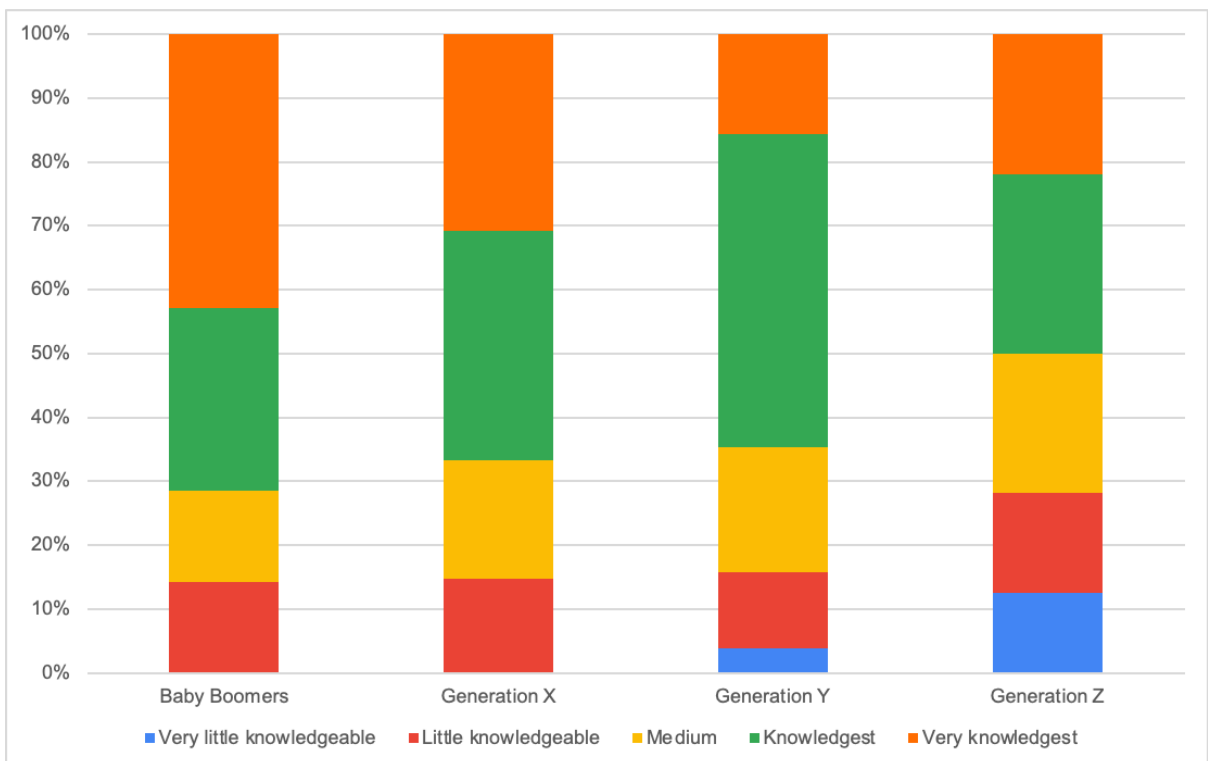
Question 7



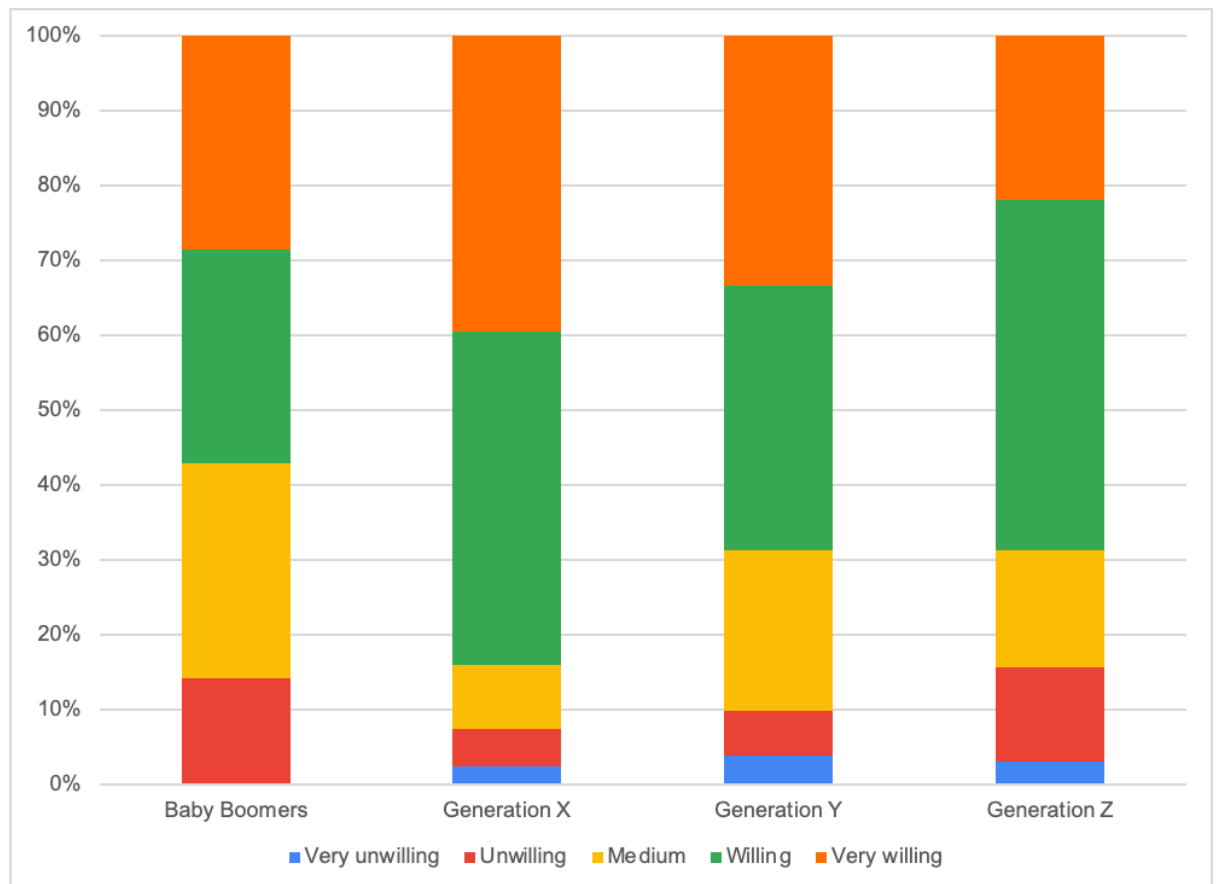
Question 8



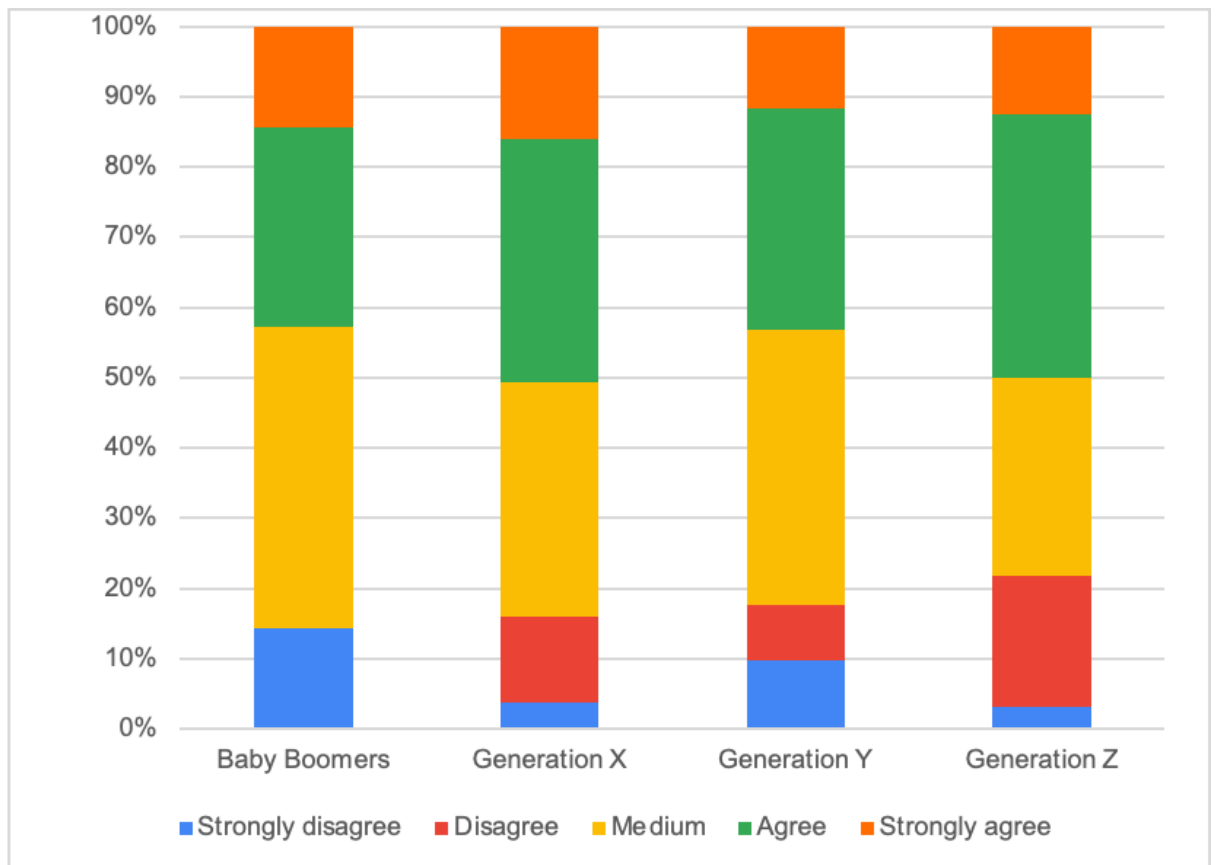
Question 9



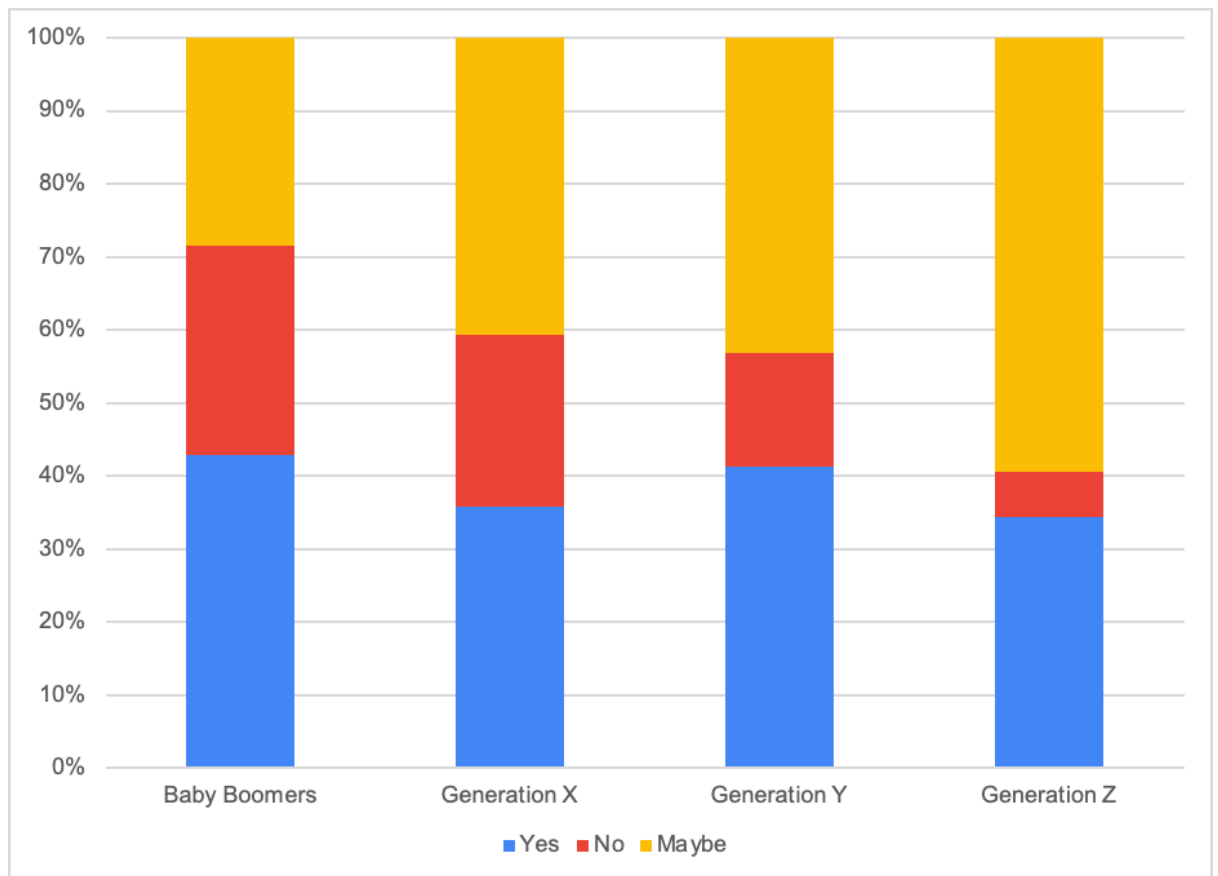
Question 10



Question 11

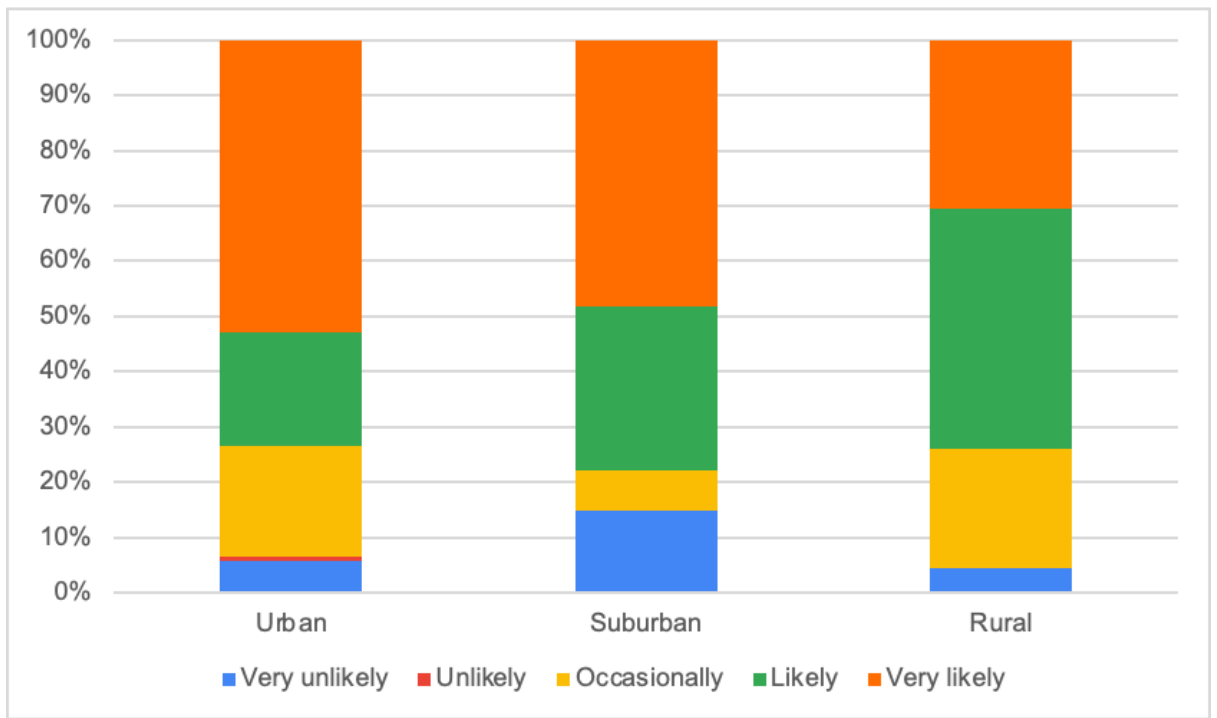


Question 12

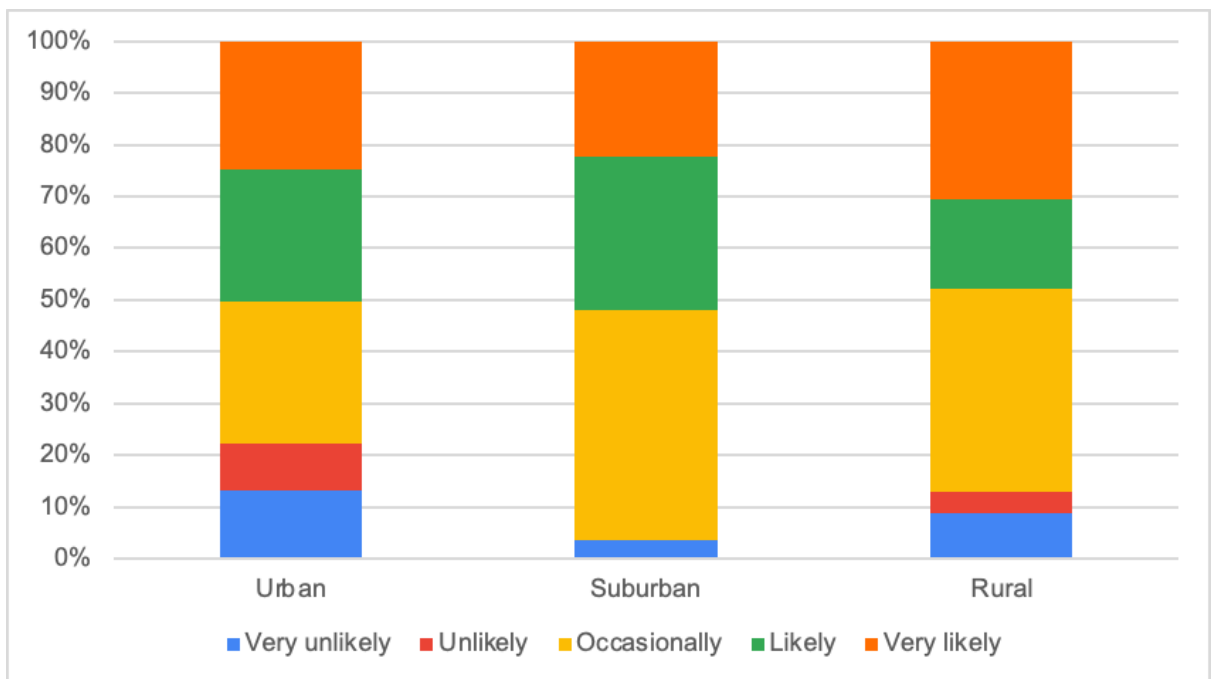


Appendix A.d. Demographic question 3 (Residence place) compared to the questions in the survey

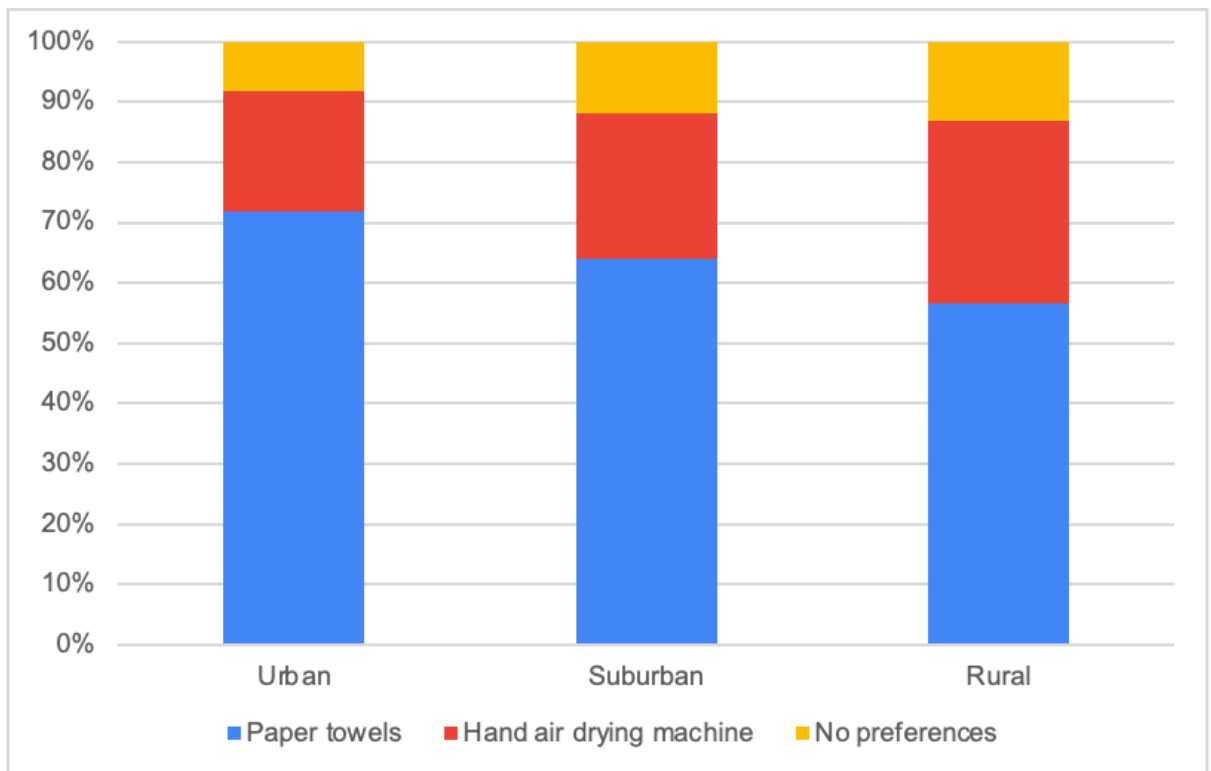
Question 1



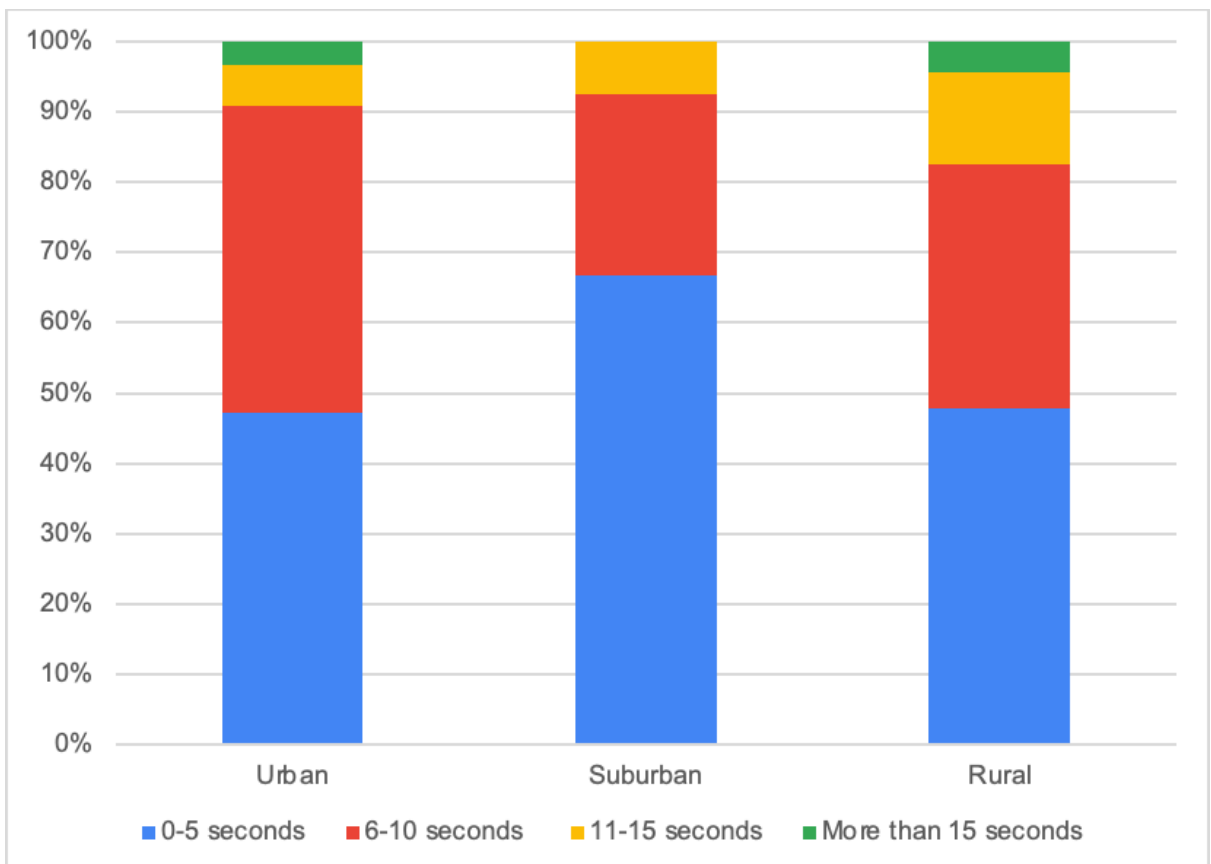
Question 2



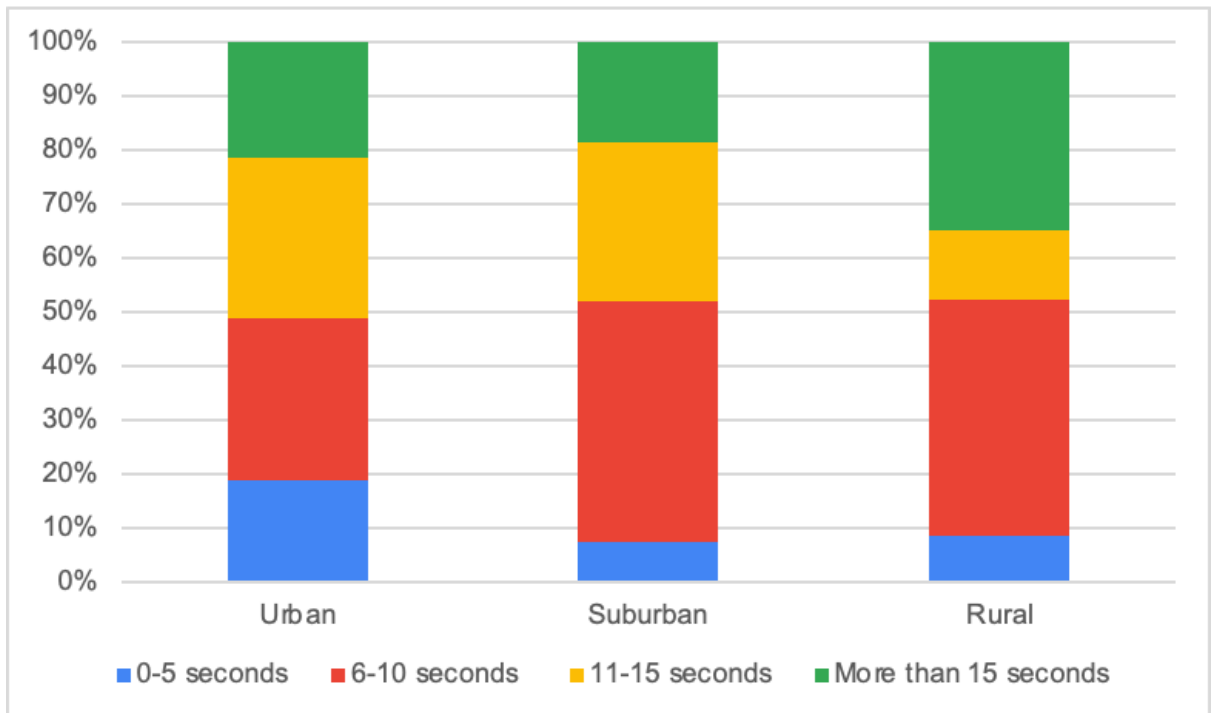
Question 3



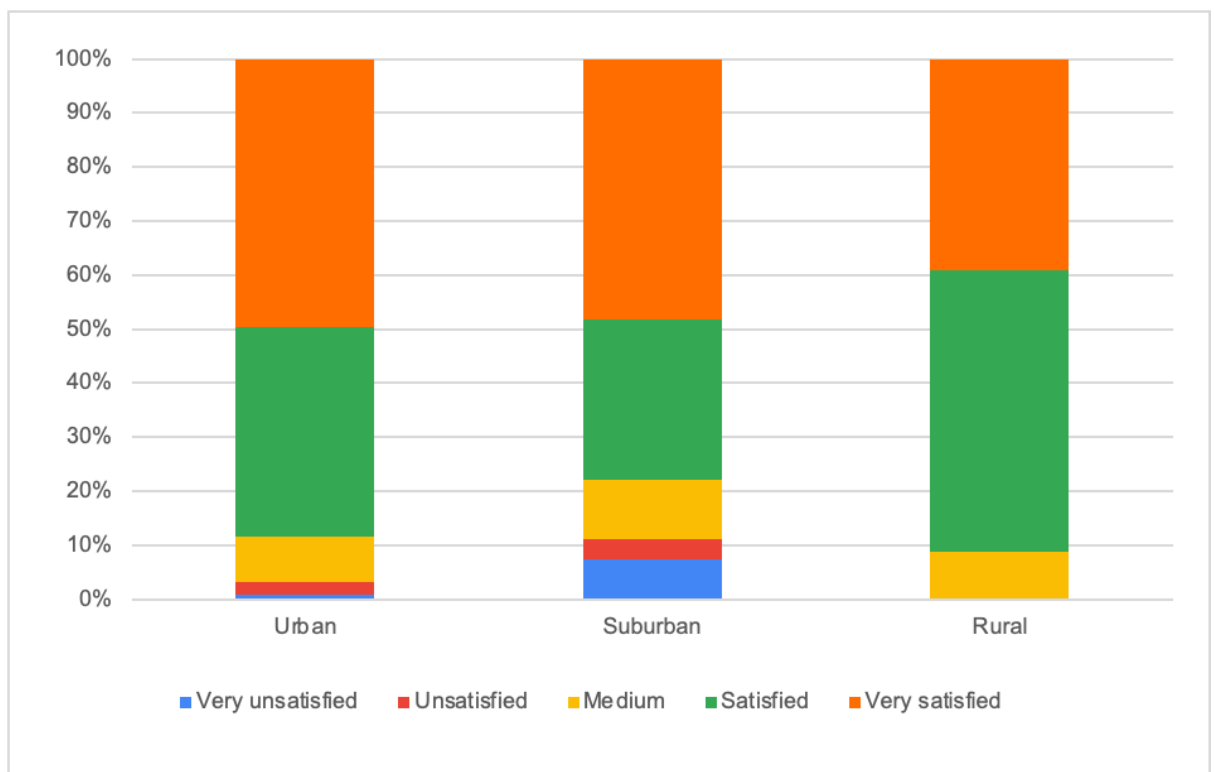
Question 4



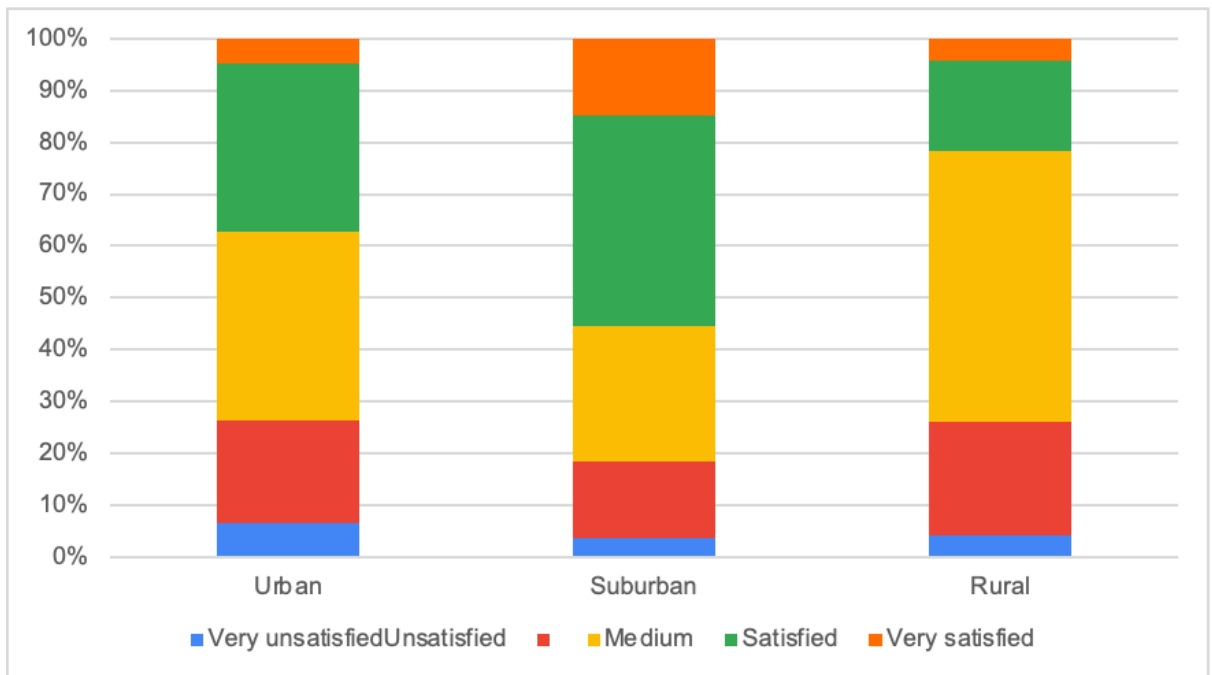
Question 5



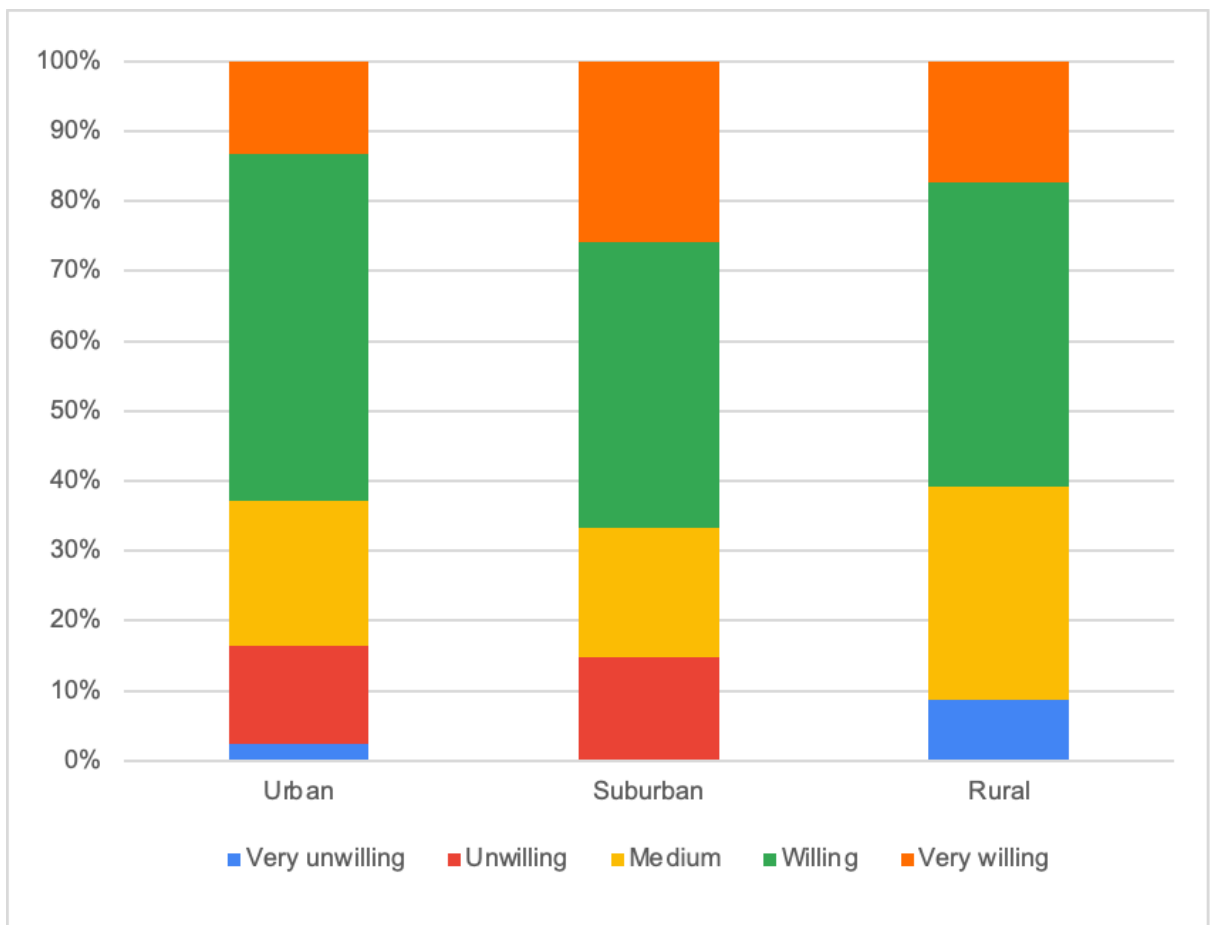
Question 6



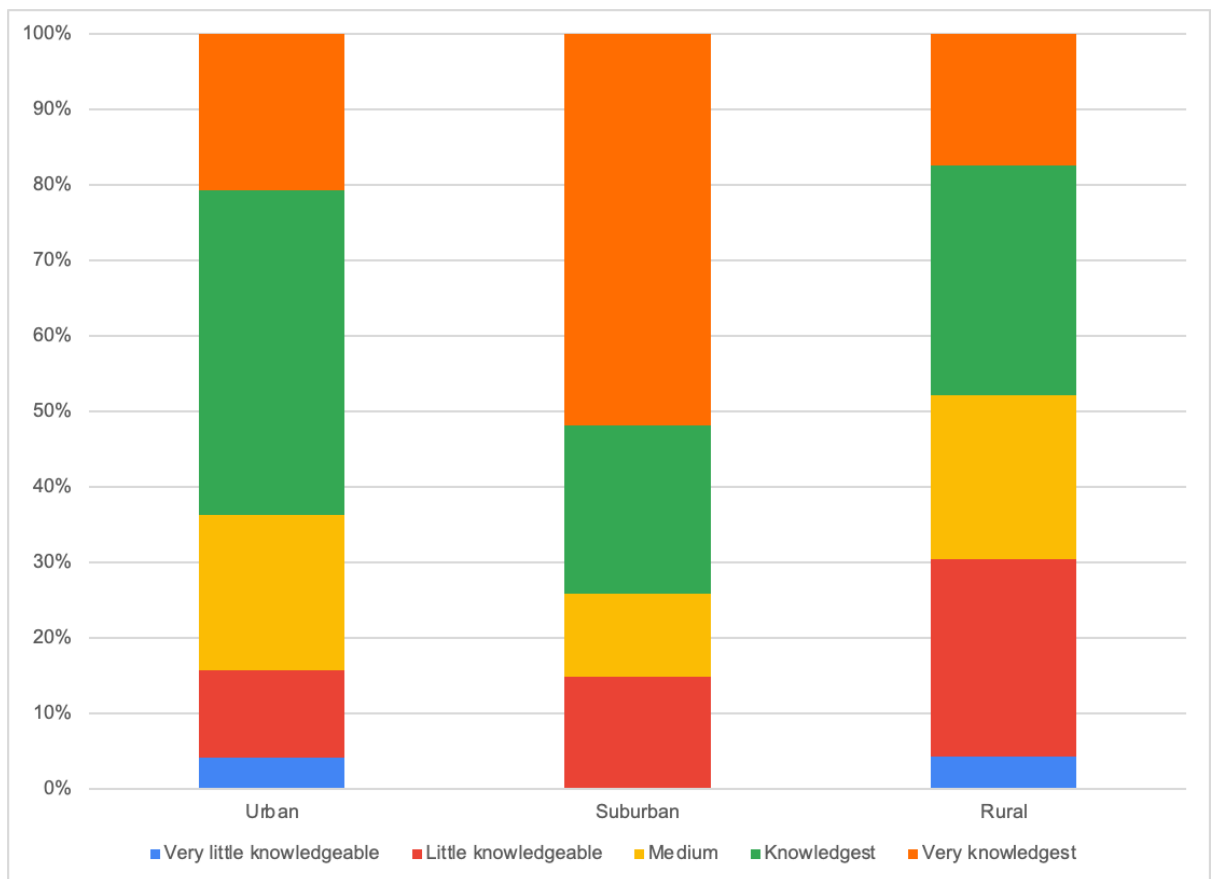
Question 7



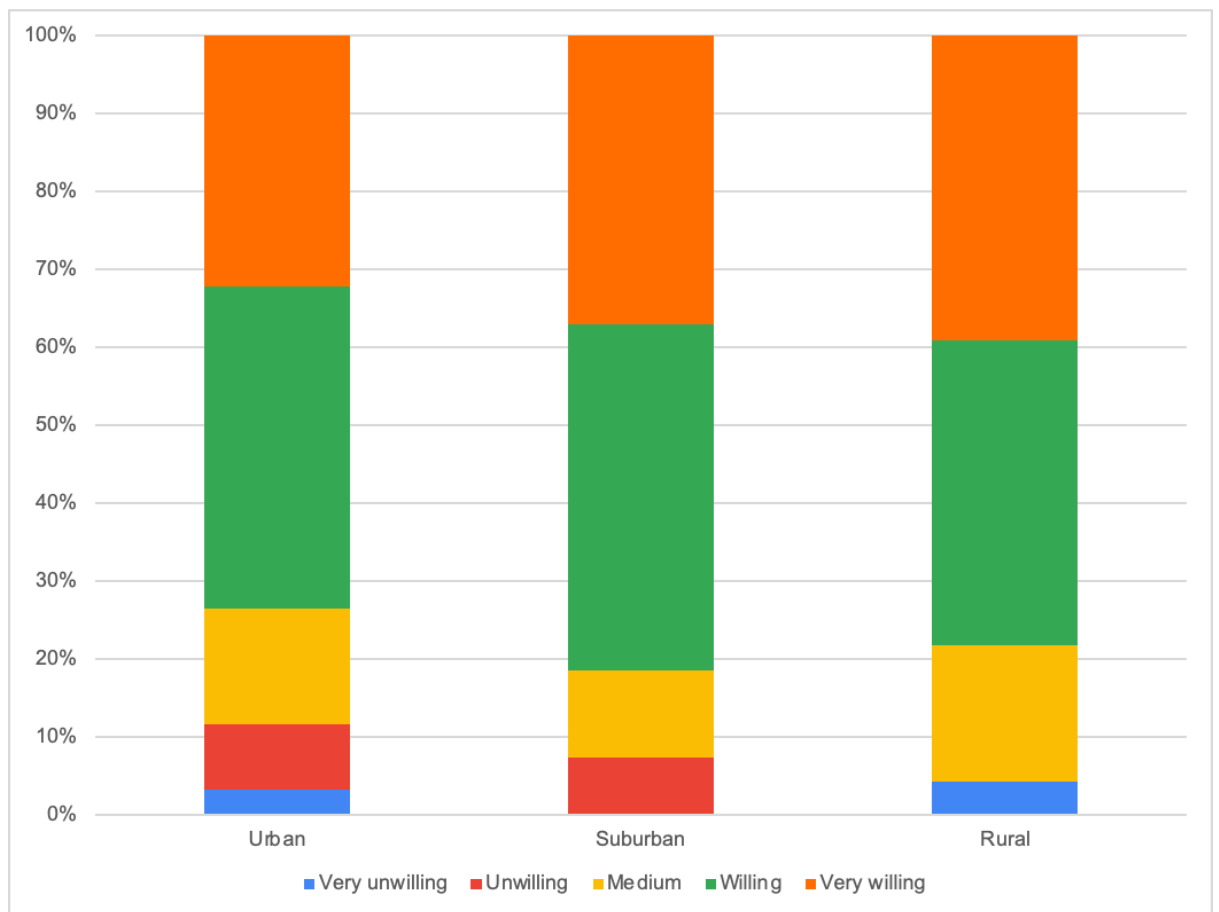
Question 8



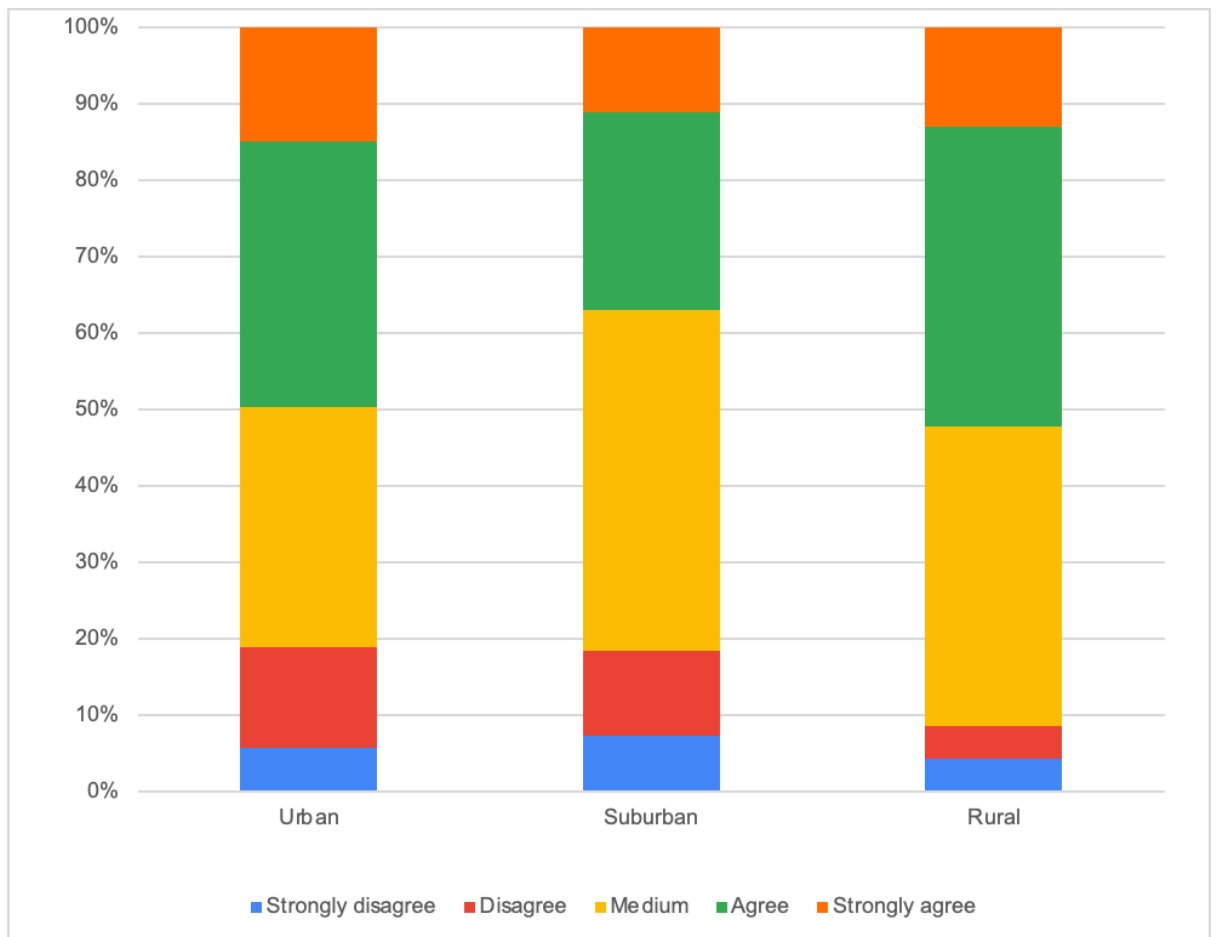
Question 9



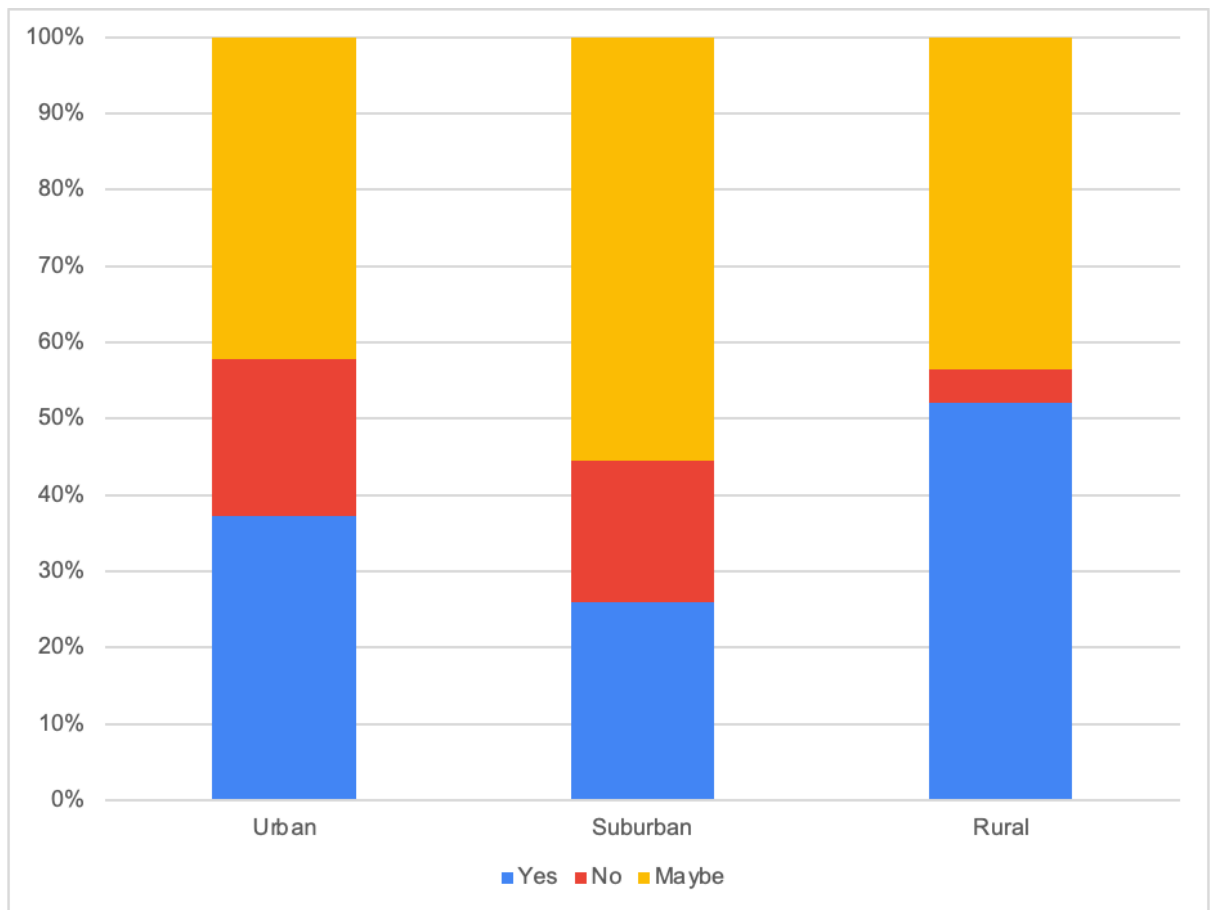
Question 10



Question 11

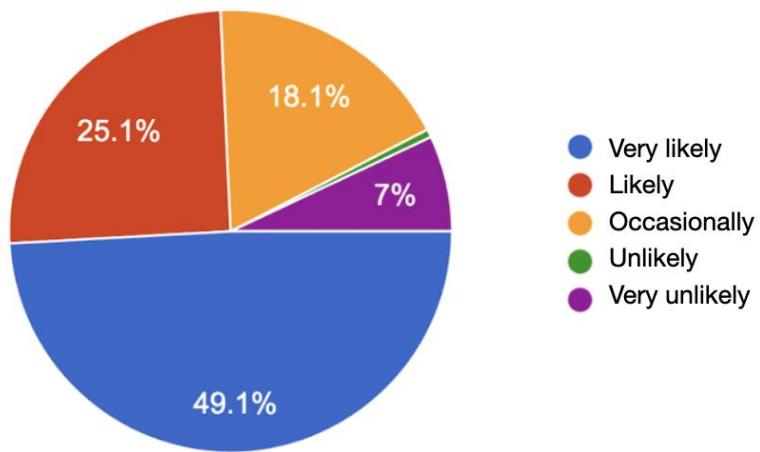


Question 12

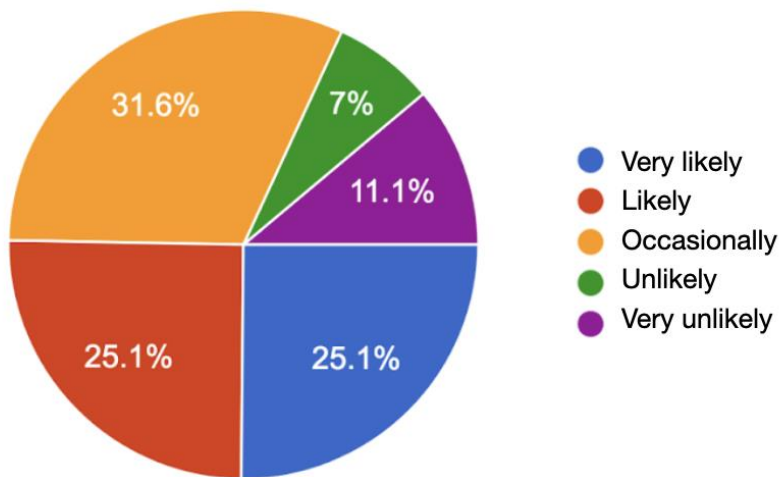


Appendix A.e. Global survey results

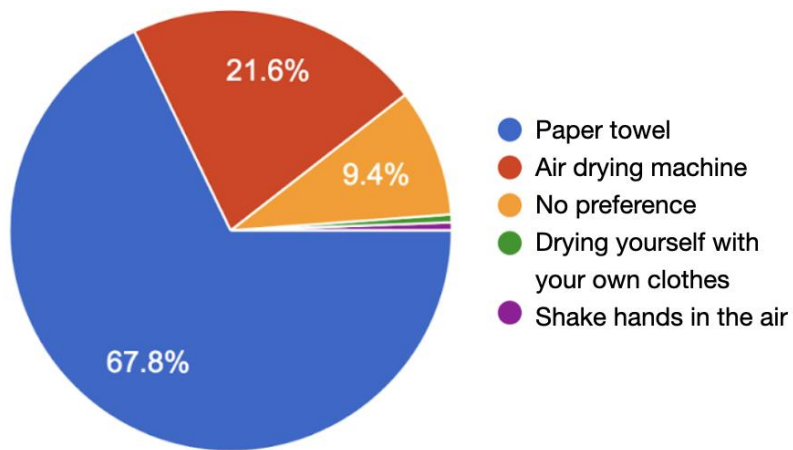
Question 1



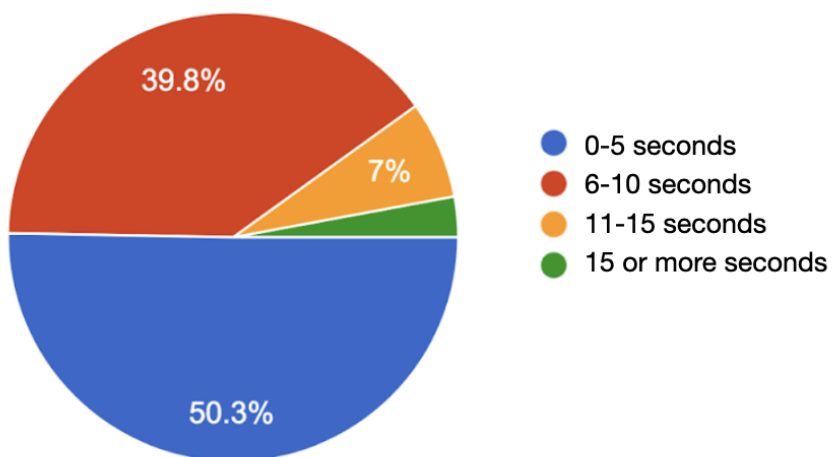
Question 2



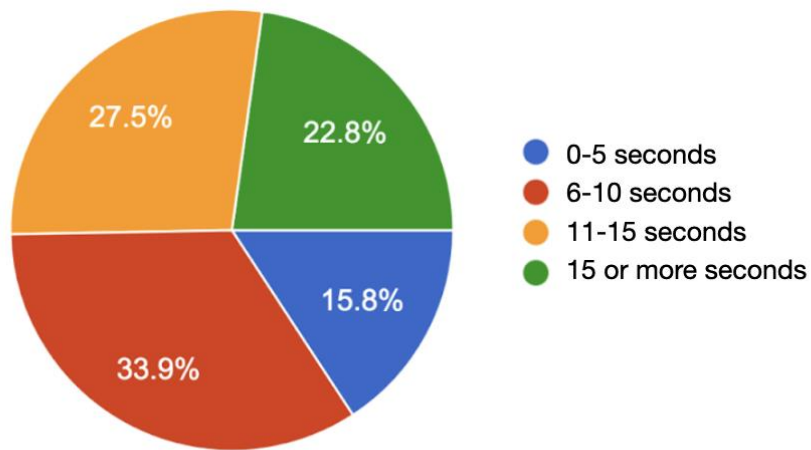
Question 3



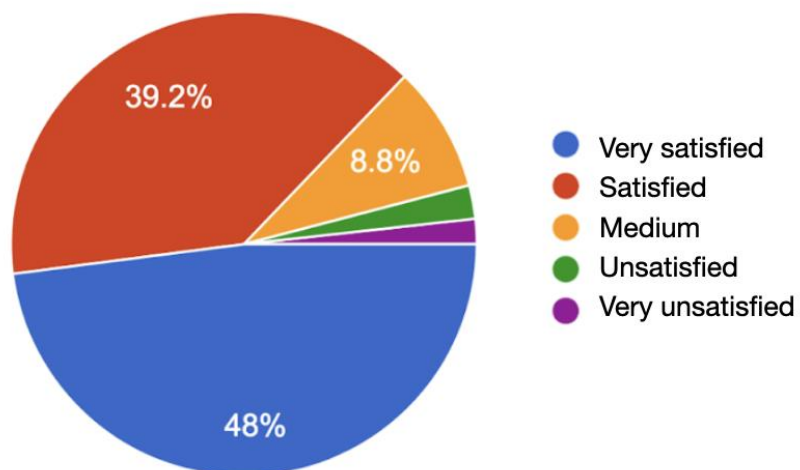
Question 4



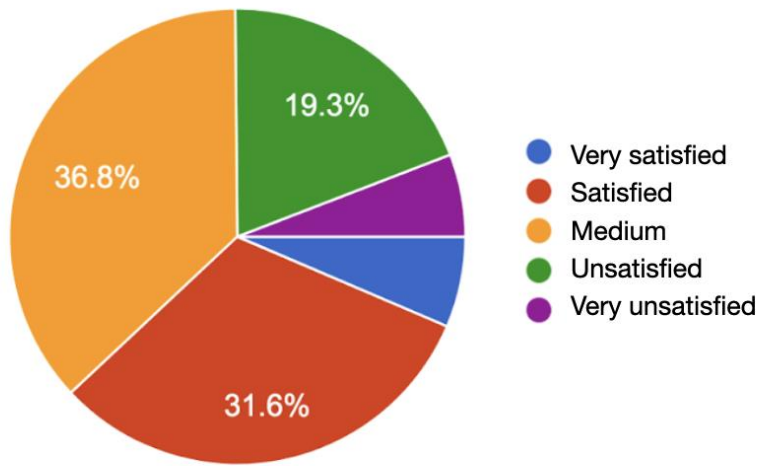
Question 5



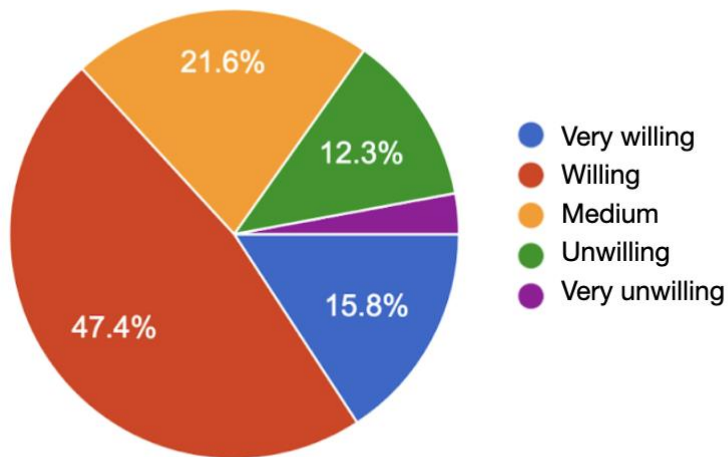
Question 6



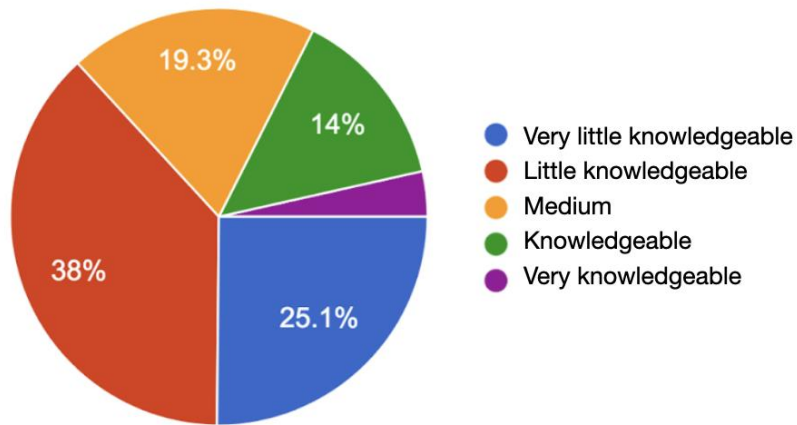
Question 7



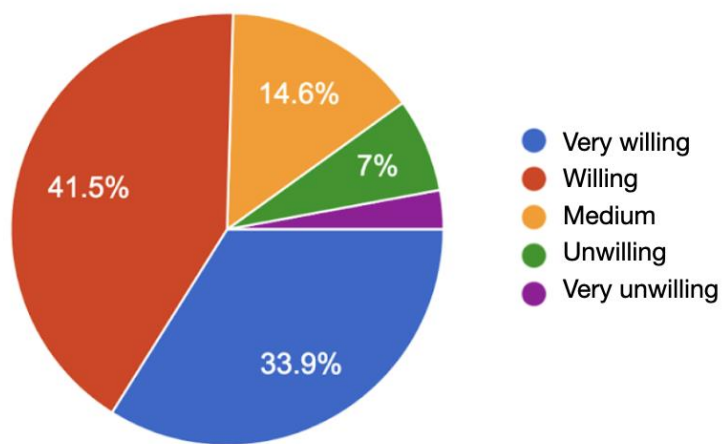
Question 8



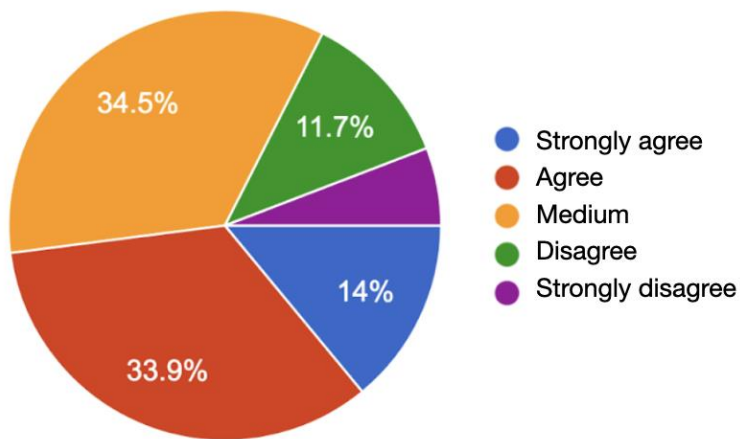
Question 9



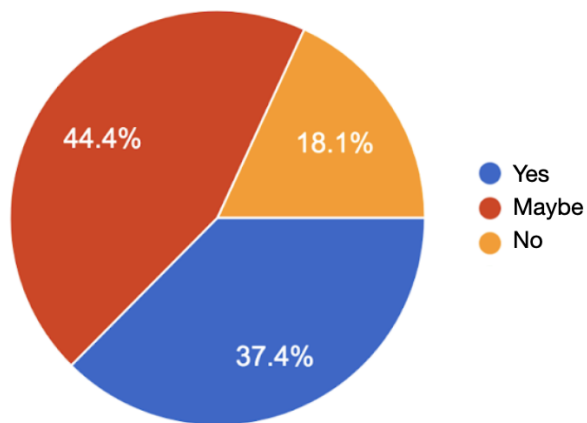
Question 10



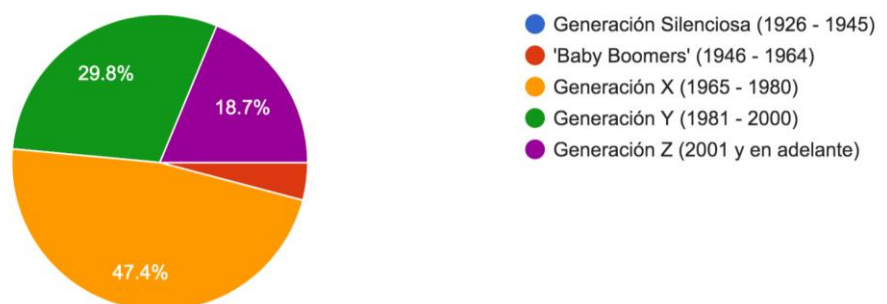
Question 11



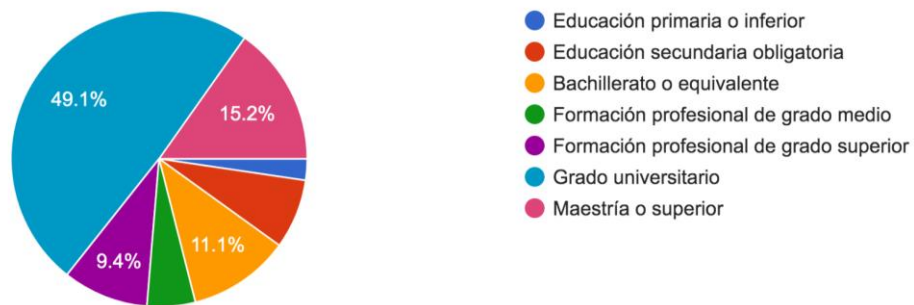
Question 12



Demographic question 1



Demographic question 2



Demographic question 3

