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ENCLUDE
Energy Citizens for Inclusive Decarbonization

D4.3 – Report on bridging clusters for decarbonization with energy models

WP4 – Identification of citizens' clusters for decarbonization

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Preface

The overall vision of ENCLUDE is to help the EU to fulfil its promise of a just and inclusive decarbonization pathway through sharing and co-creating new knowledge and practices that maximize the number and diversity of citizens who are willing and able to contribute to the energy transition. Motivated by achieving an equitable and sustainable future and the fulfilment of individual potential, ENCLUDE will contribute to the upcoming transformation of energy use by: (1) Assembling, aligning, and adapting disparate energy citizenship concepts for diverse communities of citizens and for different scales of policy making, lowering the barrier for action. (2) Operationalizing the energy citizenship concept at all scales of policy making for decarbonization. (3) Catalyzing a chain reaction of decarbonization actions across the EU.

1. Changes with respect to the DoA

This deliverable was originally due at M36. However, following the no-cost extension to the project, the new deadline was set to M40.

2. Dissemination and uptake

This deliverable will be disseminated via the project's webpage and added to the Enlighten repository of the University of Glasgow. In addition, its release will be advertised through the media channels of the consortium and of the University of Glasgow. It is expected that this deliverable will contribute to further research into individual and collective citizens' actions in the context of mitigation of and adaptation to climate change.

3. Short Summary of results (<250 words)

This deliverable presents key results on bridging clusters for energy modes by investigating clusters based on sociodemographic, energy consumption, carbon footprint, and psychological attributes. In the first WP4 deliverable (D4.1), earlier studies were explored based on the patterns of sociodemographic variables, psychological characteristics, and energy consumption data, and how these could be used to cluster groups of citizens. In the second WP4 deliverable (Naderian et al., 2024), three countries (UK, Greece, and The Netherlands) were considered from the earlier ECHOES ("Energy CHOices supporting the Energy Union and the SET-Plan") project and the k-means clustering method was used to cluster citizens based on their energy consumption and carbon footprint.

This deliverable aims to analyze citizens' clusters based on sociodemographics and psychological attributes such as age, education, house size, car fuel consumption, and climate change perception. Within-cluster analyses are carried out for citizens of the ECHOES and ENCLUDE dataset. The ENCLUDE data set includes citizens who participated in energy initiatives in Europe. Due to the qualitative nature of the ENCLUDE data set, an index-based clustering approach is presented to classify citizens.

Based on within-cluster analyses of the ECHOES data, a set of citizens' profiles have been introduced that - together with the outcomes of the index-based ENCLUDE data clustering - can be used to draw comprehensive narratives for energy models and net zero scenarios development.

The series of analyses presented in this report constitute a systematic framework for future application to more countries and/or new data sets, with the opportunity to bridge to energy and scenario models at different scales (from community to district, city, national, and supranational).

4. Evidence of accomplishment

This report serves as evidence of accomplishment.

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2	UNIVERSITY OF PIRAEUS RESEARCH CENTER	UPRC	Greece	
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6	JOANNEUM RESEARCH FORSCHUNGSGESELLSCHAFT MBH	JR	Austria	
7	TH!NK E	THNK	Belgium	
8	UNIVERSITEIT UTRECHT	UU	Netherlands	
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11	MISSIONS PUBLIQUES	MP	France	
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13	UNIVERSITY OF VICTORIA	Uvic	Canada	

Executive Summary

This deliverable presents key results on bridging clusters for decarbonization with energy models based on within-cluster analysis and citizens' profiles definitions. In the previous Work Package 4 deliverable ("*Deliverable 4.2: Report on the identification of citizens' clusters for decarbonization*"), a machine learning model was applied to the ECHOES data set to identify distinct clusters. The model workflow started from the citizens' energy consumption for the housing and mobility sectors, to then calculate the corresponding carbon footprint for those same sectors. The k-means clustering method was applied to the energy consumption and carbon footprint data for both the housing and mobility sectors to identify distinct citizens' groups in the UK, Greece, and The Netherlands (referred to as 'selected countries' in this report).

This deliverable aims to further analyze citizens of those selected countries based also on sociodemographics and psychological attributes such as age, education, house size, car fuel consumption, and climate change perception. Clustering and within-cluster analyses are carried out for the citizens of the ECHOES and ENCLUDE data sets, with the latter having been gathered as part of D3.1 (Brenner-Fliesser et al., 2023) and targeting citizens who have participated in energy initiatives in Europe. Due to the qualitative nature of the ENCLUDE data set, a bespoke index-based clustering approach is developed to classify citizens. The K-means clustering method is applied to the ENCLUDE data based on four indices: Energy Poverty Index, Energy Housing Index, Energy Mobility Index, and Climate Perception Index.

Within-cluster analysis results show that citizens of the selected countries in the ECHOES data set are mostly consuming low to medium energy in both the mobility and housing sectors. From an age and education perspective, they are mostly young people with college or university degrees. They tend to live in small houses, own cars with low fuel consumption and have a positive attitude towards the urgency of global warming. A minority of citizens show high energy consumption in either the mobility or the housing sector. This group of citizens are middle-aged or old people who own cars with higher fuel consumption or live in bigger houses. Additionally, they manifest neutral to positive climate change perception.

Based on within-cluster analyses of the ECHOES data, a set of citizens' profiles have been introduced to draw comprehensive narratives for energy models and carbon neutral scenarios. The clustering results and within-cluster analyses have led to citizens' profiles based on their sociodemographic, energy consumption, CO_2 footprint, and psychological attributes. Based on this information, as well as the outcomes of the index-based ENCLUDE data clustering, energy models can be built to assess more realistic decarbonization scenarios, for end-users (including policy makers) to be able to identify optimal options within their specific context.

The series of analyses presented in this report constitute a systematic framework for future application to more countries and/or new data sets, with the opportunity to bridge to energy and scenario models at different scales (from community to district, city, national and supranational).

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1 Introduction

1.1 Background

In the transformation of the energy system, citizens are playing a vital role in shaping its future through their active participation and engagement. The annual energy consumption of individuals is substantial and continues to rise due to population growth, leading to a corresponding increase in emissions. This trend underscores the central position of citizens in the ongoing energy transformation. Consequently, it is essential to establish a framework that can accurately measure individuals' carbon footprints and chart a course for reducing their impact on emissions. By placing citizens at the core of energy transitions, we can better address the challenges of sustainable energy use and climate change mitigation (Blasch et al., 2022; Naderian et al., 2022).

This deliverable aims to further analyze citizens of selected countries based on sociodemographic and psychological attributes such as age, education, house size, car fuel consumption, and climate change perception. Clustering and within-cluster analyses are carried out for the citizens of the ECHOES and ENCLUDE data sets, with the latter having been gathered as part of D3.1 (Brenner-Fliesser et al., 2023) and targeting citizens who have participated in energy initiatives in Europe. Due to the qualitative nature of the ENCLUDE data set, a bespoke index-based clustering approach is developed to classify citizens. The K-means clustering method is applied to the ENCLUDE data based on four indices: Energy Poverty Index, Energy Housing Index, Energy Mobility Index, and Climate Perception Index.

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Based on within-cluster analysis set of citizens' profiles have been introduced to make more meaningful and comprehensive narratives for energy models. The clustering results and within-cluster analysis of the ECHOES data have led to citizens' profiles based on their sociodemographic, energy consumption, CO2 footprint, and psychological attributes. Based on this information, as well as the outcomes of the index-based ENCLUDE data clustering, energy models could be built to assess more realistic decarbonization scenarios, for end-users (including policy makers) to be able to identify optimal options within their specific context.

1.2 Context

Within ENCLUDE, the aim of WP4 is to identify groupings of citizens (clusters for decarbonization) at different scales of analysis, so that they can be more effectively mobilized by policies to accelerate energy system decarbonization.

Individual clusters for decarbonization are not necessarily groups of citizens with common demographic characteristics; rather, they may involve demographically diverse groups sharing common characteristics of energy behavior, including readiness to embrace energy citizenship actions, which in turn result in different amounts of carbon footprint. Such groupings can inform policy makers of the citizens' profiles that are expected to be more responsive to energy citizenship policy initiatives, as these should be targeted due to their decarbonization potential.

The first task of WP4 was to identify key variables relevant to the emergence and fostering of energy citizenship that will accordingly enable the strategic clustering of citizens for decarbonization.

To this end, more than 180 journal and conference proceedings articles were reviewed in D4.1 (Sobhan Naderian et al., 2022)Click or tap here to enter text. to create a database of qualitative and quantitative attributes for the clustering process. The second task of WP4 was the development of a machine learning model for citizens clustering to extract meaningful outcomes for policy makers. Citizens of the UK, Greece and the Netherlands were considered for the clustering to find meaningful and comprehensive results helpful for policy makers. To this end, energy consumption data for the selected countries were taken from the ECHOES data set (Reichl et al., 2019), and the corresponding CO_2 footprint calculated. The results of the clustering based on energy consumption data and carbon footprint of citizens from the UK, Greece and the Netherlands were presented in D4.2 (Naderian et al., 2024). Here, the analyses are extended to include consideration of sociodemographic and psychological attributes of citizens to extract citizens' profiles that could inform energy models for the development of just carbon neutral scenarios. To this aim, additional survey data acquired from D3.1 at community energy level (Brenner-Fliesser et al., 2023) are also analyzed.

1.3 Structure of the report

This report summarizes the findings from the within-cluster analysis for the selected countries, based on clustering results of energy consumption and associated carbon footprint to extract energy citizen profiles. The report is structured as follows: firstly, within-cluster analysis based on energy consumption and carbon footprint derived from the ECHOES data set is presented in Section 2; then the emerging energy citizen profiles are shown and discussed in Section 3; afterward, clustering results of the qualitative ENCLUDE data are presented in Section 4; bridging to energy models is discussed in Section 5, and finally, the summary and conclusions are presented in Section 6.

2 Within-cluster analysis

Building upon the clustering results for energy consumption and CO_2 emissions presented in D4.2 (Naderian et al., 2024), we have evaluated each cluster for the selected countries (ECHOES data set) based on its attributes. This evaluation aims to provide valuable insights into the sociodemographics, energy consumption, and psychological factors (among others) that characterize the citizens within each identified group. Age, education, house size, car fuel consumption, and climate change perception are considered to evaluate each cluster, and the results are presented as histograms.

2.1 Within-cluster analysis for the UK

2.1.1 Energy consumption clusters

Age, education, house size, and car fuel consumption are considered, and the statistical results are presented in **Figures 1-4**. A histogram is created for each attribute within each of the energy consumptions clusters that were presented in D4.2 (Naderian et al., 2024 - in Figure 4) by counting the number of responses to ECHOES questions from citizens within that cluster.

Figure 1 shows the results for the age attribute, namely the age distribution of citizens for each cluster. The dominant age range across all clusters is 19-34 years old, except for cluster 4, where citizens older than 65 represent the largest demographic (and they are also the second largest demographic group in cluster 2). Furthermore, cluster 1 and cluster 5 have the second dominant population of individuals in the 35-49 years old age range. By analyzing each cluster based on age, policymakers can gain insight into the distribution of energy consumption across different age groups. This can inform the development of targeted policies and initiatives aimed at encouraging sustainable energy habits, particularly among young people who will play a critical role in shaping the future of the country.

The distribution of education across different clusters is presented in **Figure 2**. The results reveal that citizens with a university or college degree dominate all clusters, with a considerable population of citizens with elementary school and A-level education in cluster 2 and cluster 4. This suggests potentially limited usability of these sub-set of data when assessing if energy and emissions reduction policies should be tailored to different education levels across the population of the country.

The histograms of results for house size and car fuel efficiency are presented in **Figure 3** and **Figure 4**, respectively. They show that for all groups, the dominant answer is 50 m^2 (corresponding by default in ECHOES to the 'I don't know' choice), while for clusters 2 and 4 – which have medium to high level of energy consumption on housing - the second dominant answer is 31 to 50 m^2. The histograms suggest that energy consumption for housing is relatively consistent across all clusters, except for clusters 2 and 4. This is supported by the clustering results showing that the centroids for housing energy consumption are very close to each other, while citizens in clusters 2 and 4 tend to have bigger houses.

In the ECHOES survey, citizens were asked about their car fuel consumption if they owned a car, and the analysis of car fuel efficiency for each cluster reveals significant diversity. The centroids for mobility energy consumption are more widely dispersed in clusters 1, 3, and 5 (as depicted in Figure 4 of D4.2 (Naderian et al., 2024)).

According to the histograms presented in **Figure 4**, the dominant answer for cluster 1 is $1-2\ l/100km$, while the dominant answer for cluster 3, which has the highest energy consumption on mobility, is $4-5\ l/100km$. Also, the dominant answers for clusters 4 and 5 with low to medium level of energy consumption on mobility are $4-5\ l/100km$ and $2-4\ l/100km$, respectively, which is close to the dominant answer of cluster 3 with a high level of energy consumption on mobility. The findings of the cluster analysis on mobility energy consumption would support implementing policies aimed at increasing the use of public transport, subsidizing electric or hybrid vehiclesand informing eco-design criteria for vehicles.

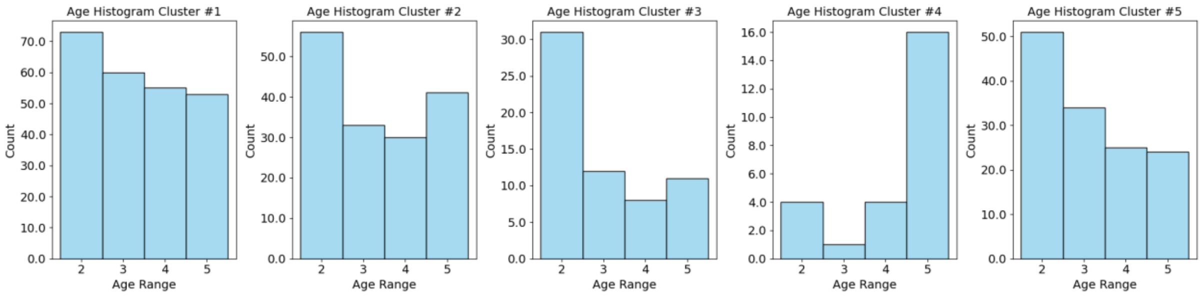

Figure 1 – Within-cluster" statistics for age attribute in the UK, x axis is citizens' answer about their age range (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

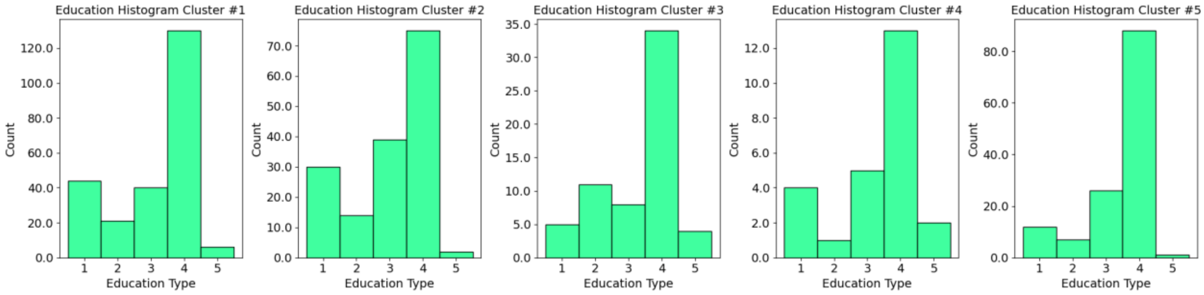

Figure 2 – Within-cluster" statistics for age attribute in the UK, x axis is citizens' answer about their age range (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

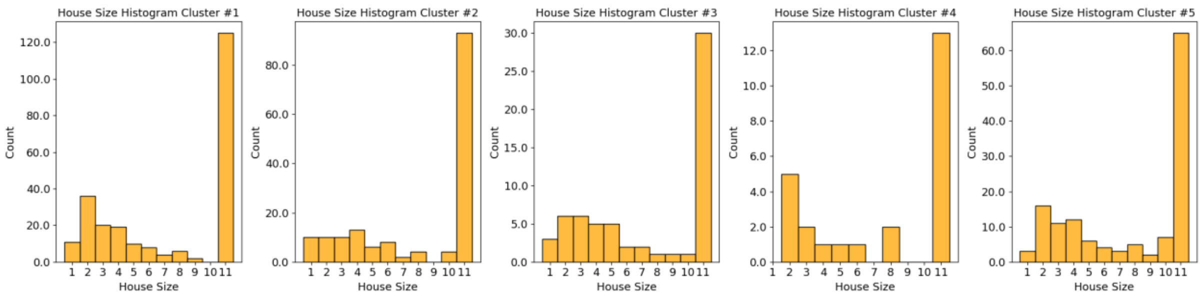

Figure 3 - "Within-cluster" statistics for house size attribute in the UK, x axis is citizens' answer about their house size (m^2) (1: <30, 2: 31-50, 3: 51-70, 4: 71-90, 5: 91-110, 6: 111-130, 7: 131-150, 8: 151-170, 9: 171-190, 10: >190, 11: I don't know (50 considered a as average house size)) and y axis is population per answer.

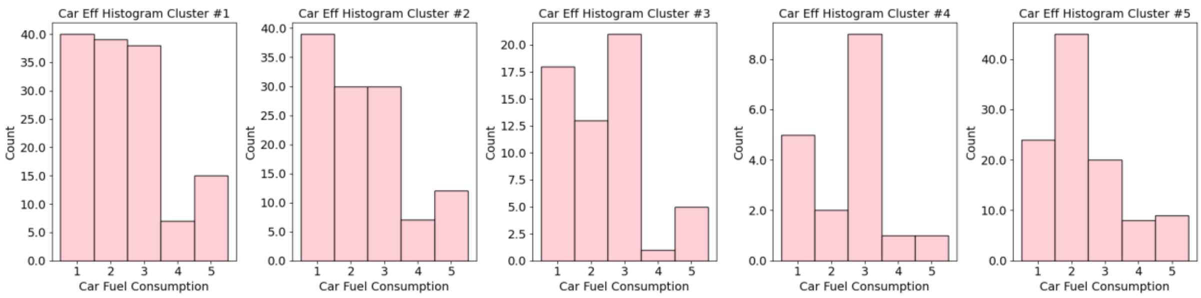

Figure 4 - "Within-cluster" statistics for car fuel efficiency attribute in the UK, x axis is citizens' answer about their car fuel efficiency (litre/(100 km)) (1: 1-2, 2: 2-4, 3: 4-5, 4: 5-7, 5: >7, 6: E/V, 7: I don't know) and y axis is population per answer.

2.1.2 CO_2 footprint clusters

The same methodology applied to the energy consumption has been implemented here; the within-cluster statistics have been derived for all four clusters to generate further insights on CO_2 footprint that were presented in D4.2 (Naderian et al., 2024 in Figure 6). The distribution of age, education, house size, car fuel efficiency and climate change perception across all clusters is presented in **Figures 5 to 9**, respectively.

From an age point of view, the dominant answer for clusters A, B, and C is 19-35 years old, but for clusters D and E it is older than 65 years and 35-49 years old, respectively. Similarly to the energy consumption results, members of this cluster with higher levels of CO_2 footprint on housing and mobility may be well-established citizens who are financially better off than the other citizens.

The dominant education level across all clusters is a university or college degree, with the second most dominant being A-level education for citizens in clusters B, C and D. This outcome suggests that the development of education-based schemes for decreasing CO_2 footprint could be helpful based on the results.

The evaluation of clusters based on house size is presented in **Figure 7**, where the dominant answer for all clusters is 50 m^2. Although, most of the citizens selected the "I don't know" answer to this question, for which 50 m^2 is then assumed, there is a notable second dominant answer for cluster 5, which is houses bigger than 190 m^2. This finding may suggest that citizens with larger houses tend to have higher CO_2 footprint on mobility because they might live with more people and have more than one vehicle.

In **Figure 8**, the histograms of car fuel efficiency show that clusters A and B have a lower CO_2 footprint due to the use of cars with lower fuel consumption. The dominant answer for these clusters is $1-2\frac{l}{100km}$, while the dominant answer for clusters C and E is higher, and particularly high for cluster E at $4-5\frac{l}{100km}$. This outcome emphasizes the importance of changing the current transportation system towards more modern and eco-friendly systems, such as electric vehicle (EV) and fuel cell electric vehicle (FCEV) as mentioned in the previous section.

Figure 9 reveals each cluster's histogram about climate change perception. The dominant answer for all clusters is "strongly agree", but for clusters with high CO_2 footprint on housing and mobility (i.e. clusters B, D, and E), there are some citizens with "moderately agree" or neutral opinion, which is a key outcome as it might directly correlate with the CO_2 footprint.

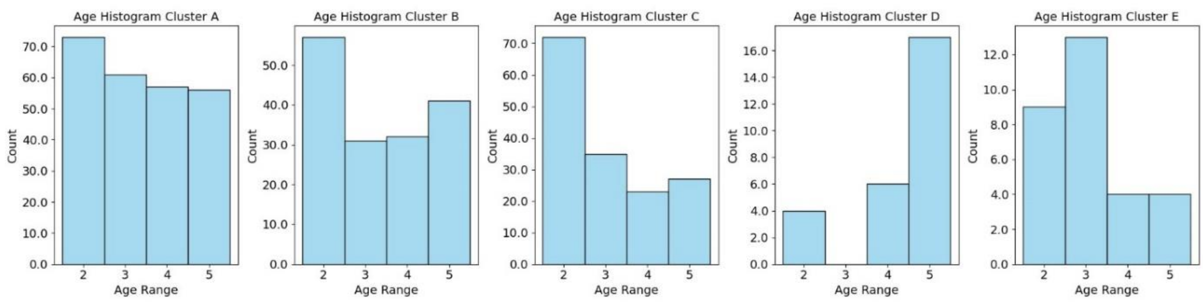

Figure 5 - "Within-cluster" statistics for age attribute, x axis is citizens' answer about their age range in the UK (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

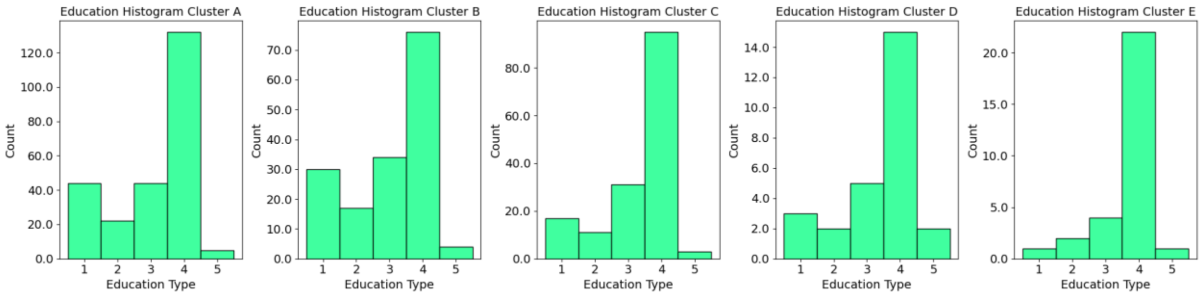

Figure 6 - "Within-cluster" statistics for education attribute in the UK, x axis is citizens' answer about their education level (1: Elementary or secondary school, 2: Professional training, 3: A-Levels, 4: University or college degree, 5: Other) and y axis is population per answer.

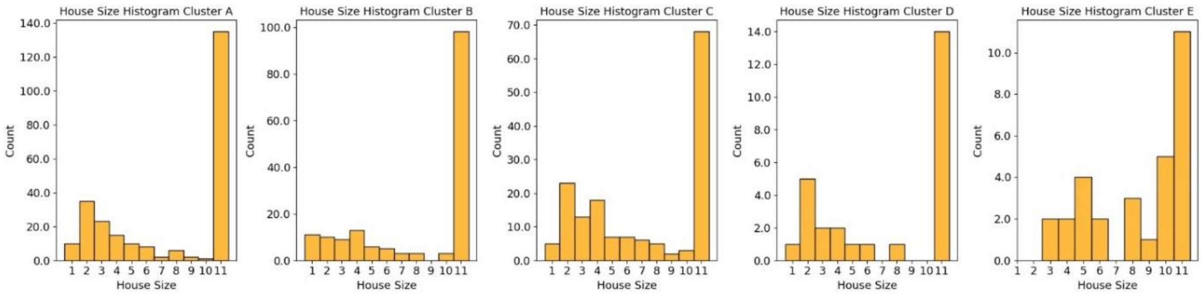

Figure 7 - "Within-cluster" statistics for house size attribute in the UK, x axis is citizens' answer about their house size (m^2) (1: <30, 2: 31-50, 3: 51-70, 4: 71-90, 5: 91-110, 6: 111-130, 7: 131-150, 8: 151-170, 9: 171-190, 10: >190, 11: I don't know (50 considered as average house size)) and y axis is population per answer.

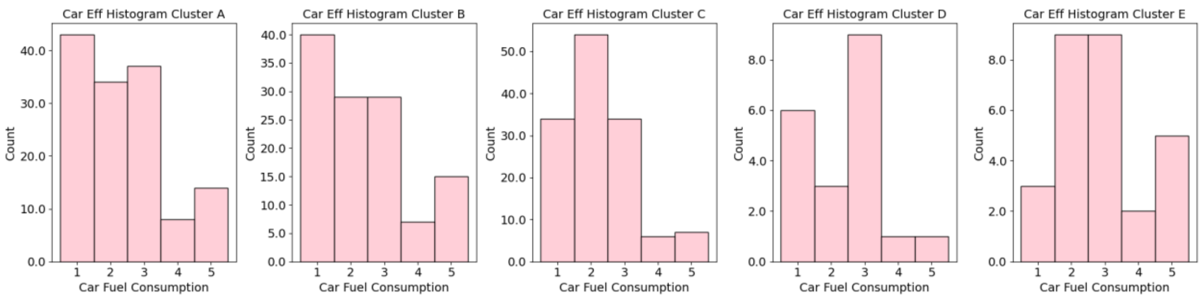

Figure 8 - "Within-cluster" statistics for car fuel efficiency attribute in the UK, x axis is citizens' answer about their car fuel efficiency (litre/(100 km)) (1: 1-2, 2: 2-4, 3: 4-5, 4: 5-7, 5: >7, 6: E/V, 7: I don't know) and y axis is population per answer.

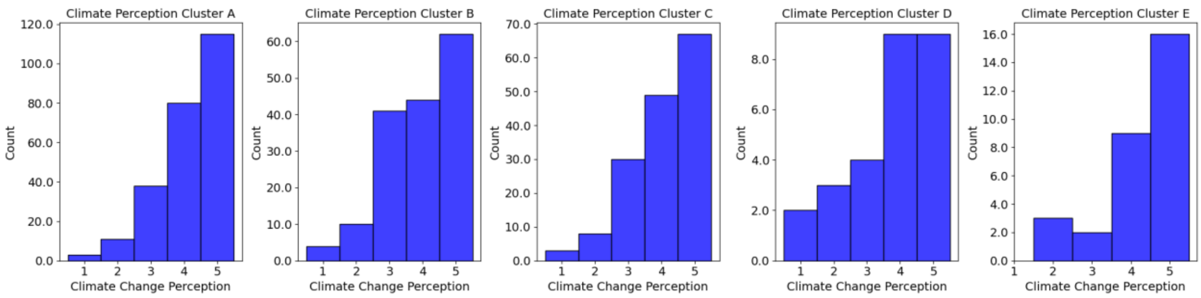

Figure 9 - "Within cluster" statistics for climate change in the UK, x axis is citizens' answer about their climate change perception) (1: Strongly disagree, 2: Moderately disagree, 3: Neither disagree nor agree, 4: Moderately agree, 5: Strongly agree) and y axis is population per answer.

2.2 Within-cluster analysis for Greece

2.2.1 Energy consumption clusters

Similar to the approach for the UK, age, education, house size and car fuel consumption have been considered as within-cluster attributes to analyze each cluster for Greece. According to the clustering results in D4.2 (Naderian et al., 2024 – in Figure 8), three clusters were identified for Greece and they are considered in this section.

Figure 10 shows the age attributes for each of three clusters where the dominant answer for all clusters is young people in 19-34 years old range while for the cluster 2 the second dominant answer is people in 35-49 years old.

As presented in **Figure 11** all the clusters have the same dominant answer regarding education which is mostly university or college degree.

Apart from the results were shown for the UK for house size, distribution of the answers for this attribute for Greece shows diverse answers and different dominant answers. **Figure 12** shows the results for all three clusters where, the dominant answers for cluster 1 are houses with 71-90 m^2 and 91-110 m^2 which is interesting because most of the UK respondents mentioned I don't know for this question. For cluster 2 with higher energy consumption in the housing sector the dominant answer is 71-90 m^2 while the second and third dominant answers are 91-110 m^2 and 111-130 m^2, respectively, which could be a justification for higher energy consumption.

According to the histograms presented in **Figure 13**, the dominant answer for cluster 1 is $2-4\ \frac{l}{100km}$, while the dominant answer and the second dominant for cluster 2 with high energy consumption on mobility sector, is $2-4\ \frac{l}{100km}$ and $4-5\frac{l}{100km}$. Also, the dominant and the second dominant answers for clusters 3 with medium to high level of energy consumption on housing are $1-2\frac{l}{100km}$ and $2-4\frac{l}{100km}$, respectively, which is a justification for low energy consumption on the mobility sector.

The findings of the cluster analysis on mobility energy consumption imply that implementing policies aimed at increasing the use of public transport and subsidizing electric or hybrid vehicles may potentially encourage citizens' energy consumption behavior change to more sustainable habits; for example, this would be applicable to the minority of citizens who tend to consume more energy on mobility and produce a higher level of CO_2.

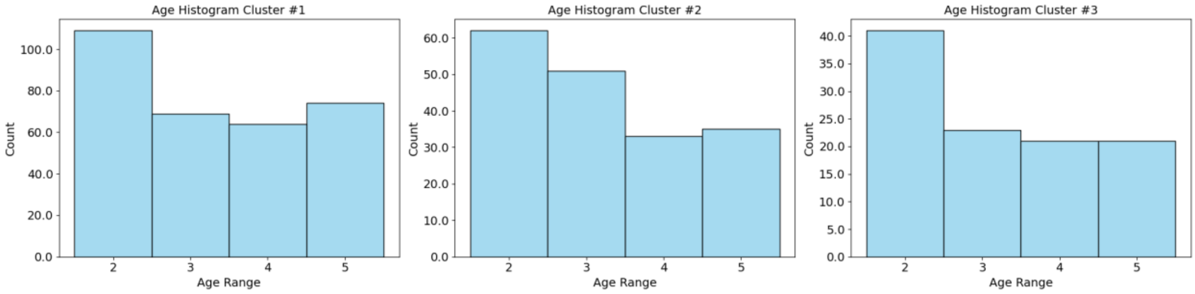

Figure 10– "Within-cluster" statistics for age attribute in Greece, x axis is citizens' answer about their age range. (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

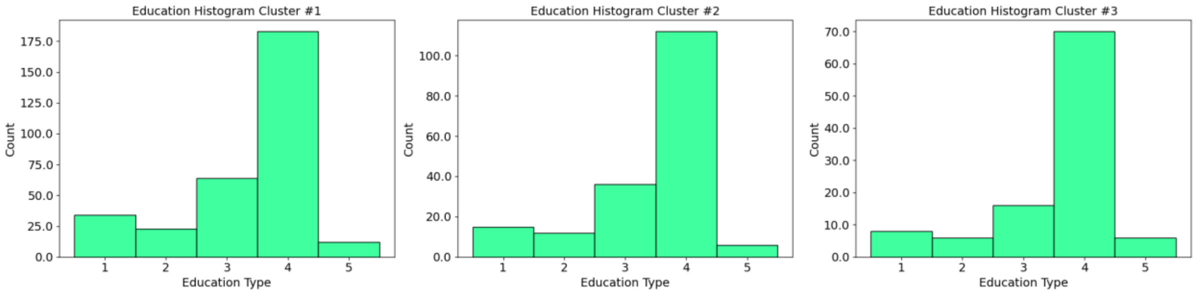

Figure 11 - “Within-cluster” statistics for education attribute in Greece, x axis is citizens’ answer about their education level (1: Elementary or secondary school, 2: Professional training, 3: A-Levels, 4: University or college degree, 5: Other) and y axis is population per answer.

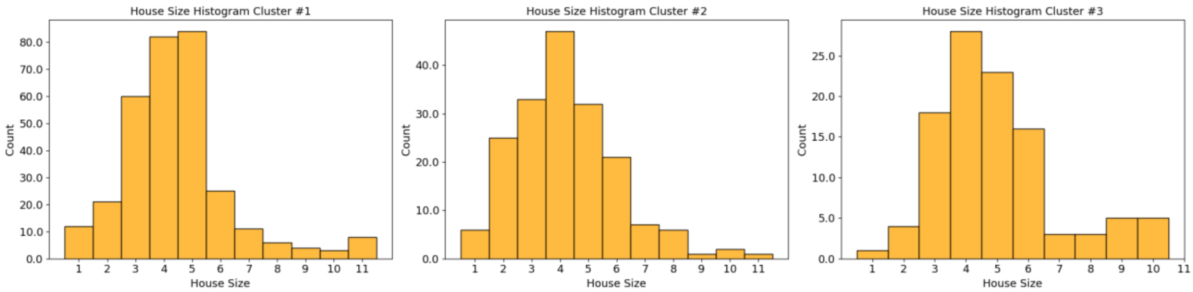

Figure 12 - “Within-cluster” statistics for house size attribute in Greece, x axis is citizens’ answer about their house size (m^2) (1: <30, 2: 31-50, 3: 51-70, 4: 71-90, 5: 91-110, 6: 111-130, 7: 131-150, 8: 151-170, 9: 171-190, 10: >190, 11: I don’t know (50 considered as average house size)) and y axis is population per answer.

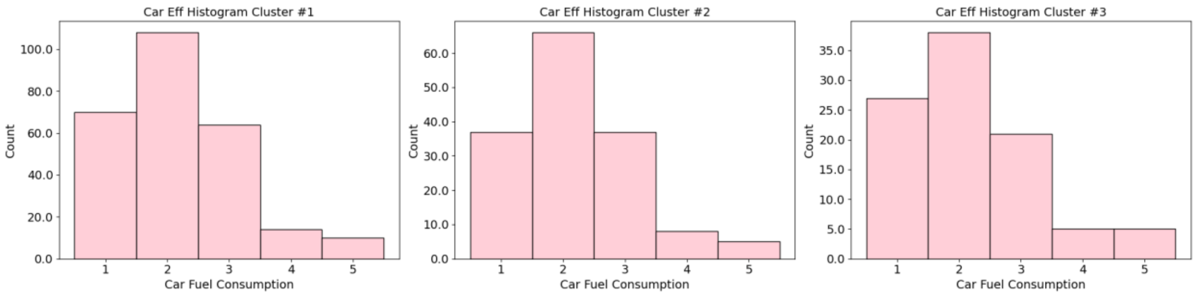

Figure 13 - “Within-cluster” statistics for car fuel efficiency attribute in Greece, x axis is citizens’ answer about their car fuel efficiency (litre/(100 km)) (1: 1-2, 2: 2-4, 3: 4-5, 4: 5-7, 5: >7, 6: E/V, 7: I don’t know) and y axis is population per answer.

2.2.2 CO_2 footprint clusters

As discussed in the D4.2 (Naderian et al., 2024) citizens of the selected countries have been clustered based on their energy consumption and CO_2 footprint to create comprehensive results and meaningful outcomes. Here within-cluster analysis has been carried out for Greece based on carbon emissions estimates for each respondent as already presented in D4.2 (Naderian et al., 2024 - in Figure 9).

Figures 14-18 represent the within-cluster results and histograms for Greece and for the same attributes were considered for the UK analysis. Similar to energy consumption three clusters were considered.

Figure 14 shows the age attributes where the dominant answer for all clusters is young people in the 19-34 years old range while the distribution is slightly different compared to energy consumption results. For instance, the second dominant answer for both cluster 1 and cluster 2 is people in 35-49 years old while the second dominant answer for cluster 3 with high CO_2 emissions in housing sector is mostly older people in 50-65 years old and people older than 65 years old.

As presented in **Figure 15**, all the clusters have the same dominant answer regarding education which is university or college degree.

Figure 16 shows the results for house size attributes for all three clusters. The dominant answers for cluster 1 are houses with 71-90 m^2 and 91-110 m^2. For cluster 2 with higher energy consumption in the housing sector the dominant answer is 71-90 m^2 while the second dominant answer is 91-110 m^2 which could be a justification for higher energy consumption. Regarding car fuel consumption, the same results repeated for CO_2 footprint as **Figure 17** represents them and the dominant answers for cluster 2 with higher CO_2 footprint in mobility sector, are $2-4\ \frac{l}{100km}$ and $4-5\frac{l}{100km}$ which is higher compared to the dominant answer of cluster 1 and cluster 3.

Figure 18 represents each cluster's histogram about climate change perception. The dominant answer for all clusters is "strongly agree", but for cluster 2 with high CO_2 footprint on mobility), there are some citizens with "moderately agree" opinion as second dominant answer, which is a key outcome as it might directly correlate with the high CO_2 footprint on mobility.

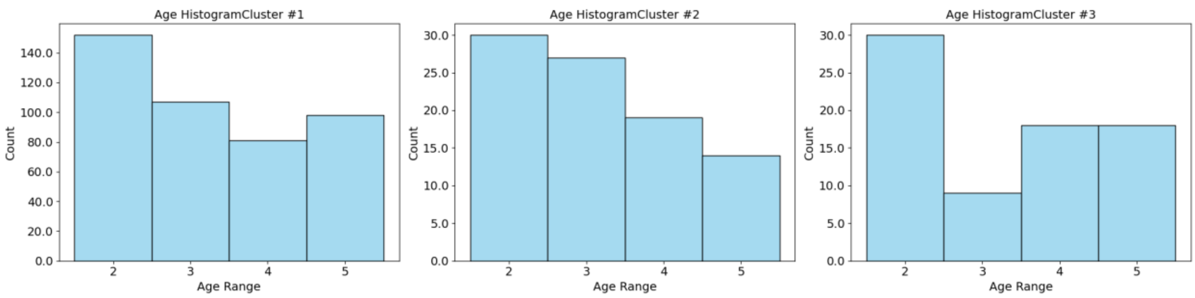

Figure 14 - "Within-cluster" statistics for age attribute in Greece, x axis is citizens' answer about their age range. (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

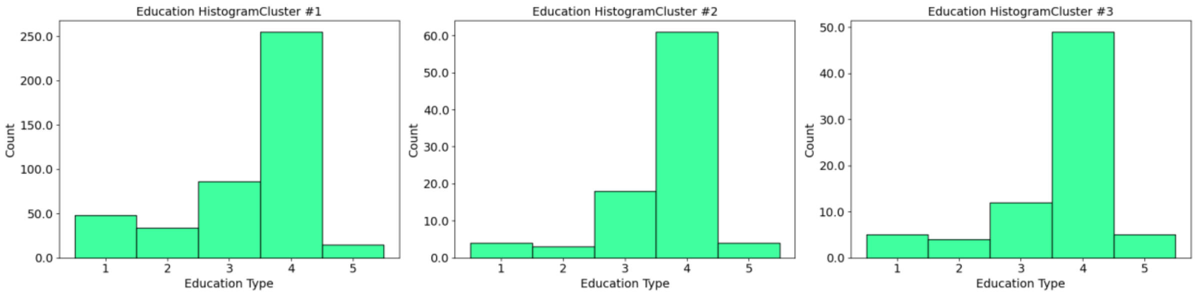

Figure 15 - "Within-cluster" statistics for education attribute in Greece, x axis is citizens' answer about their education level (1: Elementary or secondary school, 2: Professional training, 3: A-Levels, 4: University or college degree, 5: Other) and y axis is population per answer.

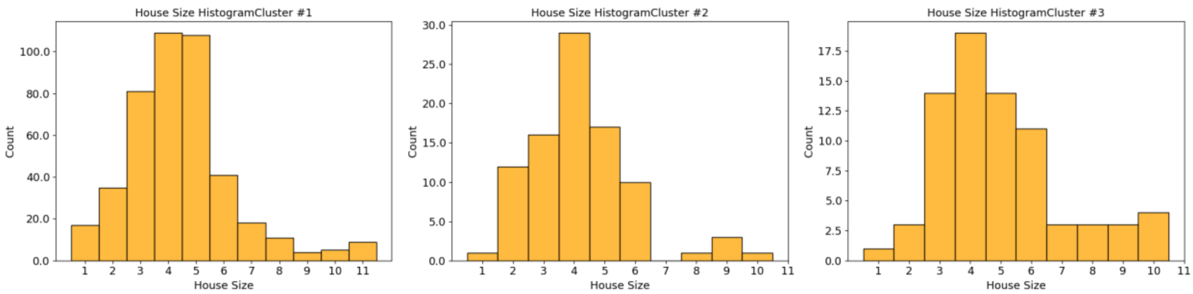

Figure 16 - "Within-cluster" statistics for house size attribute in Greece, x axis is citizens' answer about their house size (m2) (1: <30, 2: 31-50, 3: 51-70, 4: 71-90, 5: 91-110, 6: 111-130, 7: 131-150, 8: 151-170, 9: 171-190, 10: >190, 11: I don't know (50 considered as average house size)) and y axis is population per answer.

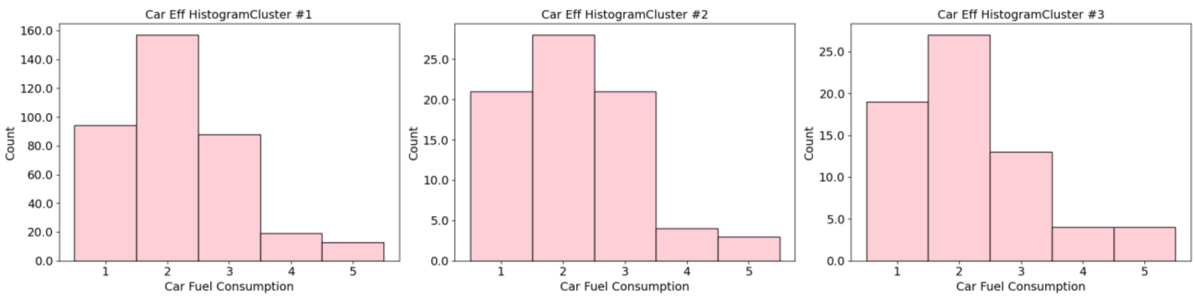

Figure 17 - "Within-cluster" statistics for car fuel efficiency attribute in Greece, x axis is citizens' answer about their car fuel efficiency (litre/(100 km)) (1: 1-2, 2: 2-4, 3: 4-5, 4: 5-7, 5: >7, 6: E/V, 7: I don't know) and y axis is population per answer.

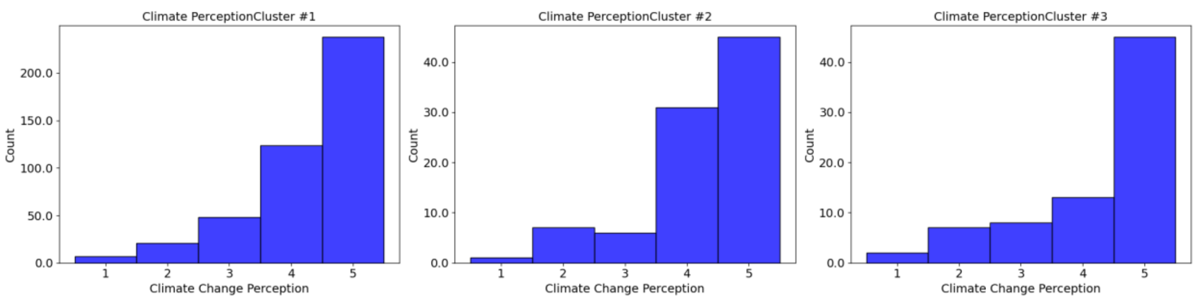

Figure 18 - "Within cluster" statistics for climate change in Greece, x axis is citizens' answer about their cli-mate change perception) (1: Strongly disagree, 2: Moderately disagree, 3: Neither disagree nor agree, 4: Moderately agree, 5: Strongly agree) and y axis is population per answer.

2.3 Within-cluster analysis for the Netherlands

2.3.1 Energy consumption clusters

The Netherlands is the third country from the selected countries that were discussed in D4.2 (Naderian et al., 2024) (please refer to Figure 10 for clustering results of the Netherlands) and in this section will be analyzed based on same attributes considered for the other selected countries. **Figures 19-22** represent the within-clustering results and histograms for the Netherlands based on age, education, house size, and car fuel consumption.

Figure 19 shows the age attributes for each of four clusters where the dominant answer for both cluster 1 and cluster 4 are young people in 19-34 years old range while for cluster 2 the dominant answer is people between 35-49 years old. Additionally, the dominant answer for cluster 3 is young (19-34 years old) and old (>65 years old) people simultaneously.

As presented in **Figure 20** all the clusters have the same dominant answer regarding education which is university or college degree, except cluster 3 where the dominant answer for citizens is professional training and it is also the second dominant answer for cluster 1.

The distribution of the answers for house size for the Netherlands shows diverse answers and different dominant answers. **Figure 21** shows the results for all four clusters. For instance, the dominant answers for cluster 1 are houses with 111-130 m^2. For cluster 4 with higher energy consumption in the mobility sector the dominant answers are 71-90 m^2 and 91-110 m^2 , respectively, while the dominant answer for cluster 3 is "*I don't know*".

According to the histograms presented in **Figure 22**, the dominant answers for cluster 1 is $2-4\ \frac{l}{100km}$ and $4-5\frac{l}{100km}$. The dominant answer for cluster 4 with high energy consumption on mobility sector, is $4-5\frac{l}{100km}$. Both cluster 1 and cluster 4 have medium to high energy consumption in the mobility sector, particularly cluster 4 which has the highest energy consumption in this sector. These findings could imply the relation between high energy consumption and owning cars with high fuel consumption.

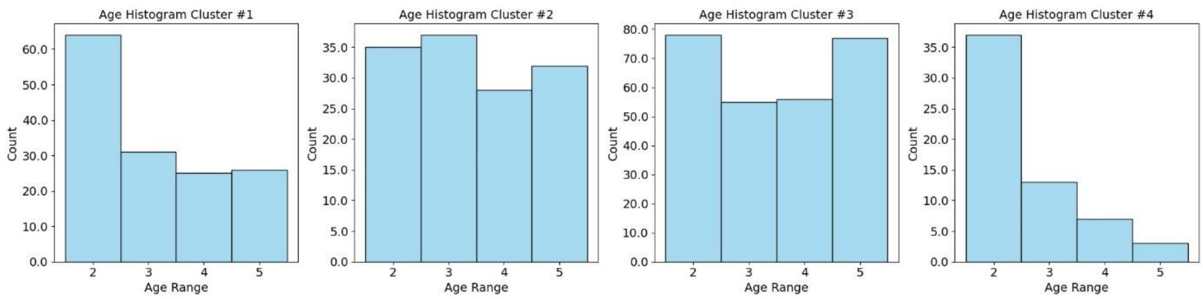

Figure 19 - "Within-cluster" statistics for age attribute in the Netherlands, x axis is citizens' answer about their age range. (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

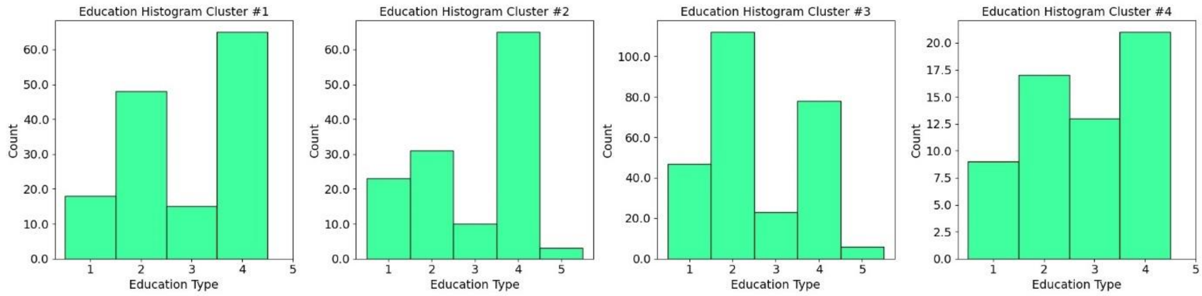

Figure 20 - "Within-cluster" statistics for education attribute in the Netherlands, x axis is citizens' answer about their education level (1: Elementary or secondary school, 2: Professional training, 3: A-Levels, 4: University or college degree, 5: Other) and y axis is population per answer.

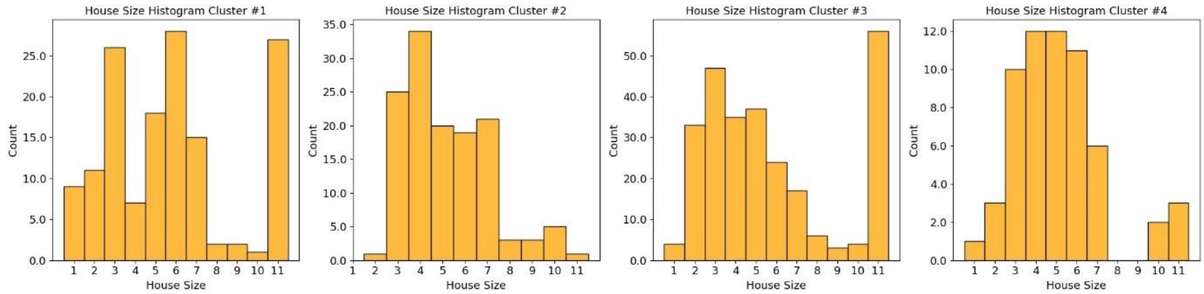

Figure 21 - "Within-cluster" statistics for house size attribute in the Netherlands, x axis is citizens' answer about their house size (m2) (1: <30, 2: 31-50, 3: 51-70, 4: 71-90, 5: 91-110, 6: 111-130, 7: 131-150, 8: 151-170, 9: 171-190, 10: >190, 11: I don't know (50 considered as average house size)) and y axis is population per answer.

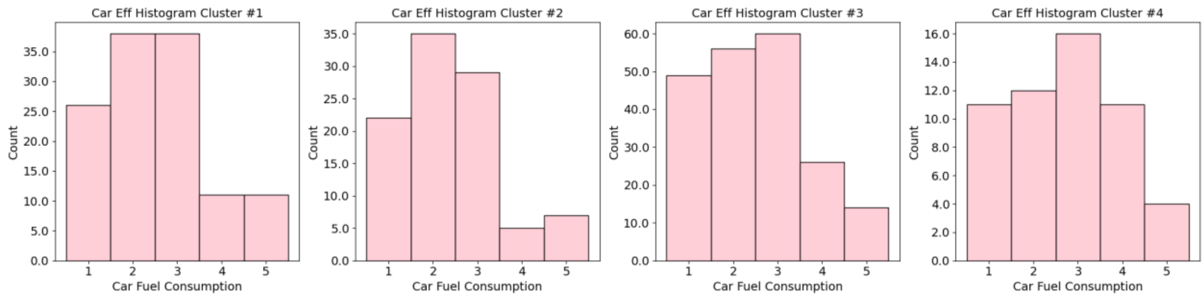

Figure 22 - "Within-cluster" statistics for car fuel efficiency attribute in the Netherlands, x axis is citizens' answer about their car fuel efficiency (litre/(100 km)) (1: 1-2, 2: 2-4, 3: 4-5, 4: 5-7, 5: >7, 6: E/V, 7: I don't know) and y axis is population per answer.

2.3.2 CO_2 footprint clusters

Similar to previous sections, **Figures 23-27** represent the within-clustering results and histograms for the Netherlands based on clustering results in D4.2 (Naderian et al., 2024) (please refer to Figure 11) for the same attributes that were considered for other selected countries. Similar to energy consumption results, four clusters were found.

Figure 23 shows the age attributes where the dominant answer for all clusters is young people in the 19-34 years old range while the distribution is slightly different compared to energy consumption results. For instance, the second dominant answer for cluster 1 and cluster 3 with medium to high CO_2 emissions is people older than 65 years old.

As presented in **Figure 24**, all clusters have the same dominant answer regarding education which is mostly university or college degree except for cluster 1 where the dominant answer is professional training and it is also the second dominant answer for cluster 2.

Figure 25 shows the results for house size attributes for all four clusters. The dominant answers for cluster 1 are houses with 51-70 m^2 and "*I don't know*". In cluster 3 with high CO_2 footprint in housing sector the dominant answer is 71-90 m^2 while the second and third dominant answers are 51-70 m^2 and 91-110 m^2 which is a justification for higher energy consumption. Regarding car fuel consumption, the slightly different results found compared to energy consumption results as **Figure 26** represents them. The dominant answers for cluster 2 with higher CO_2 footprint in the mobility sector are $2-4\frac{l}{100km}$ and $4-5\frac{l}{100km}$. Citizens in cluster 4 tend to consume more fuel for their cars as the dominant answer is $4-5\frac{l}{100km}$.

Figure 27 represents each cluster's histogram about climate change perception. The dominant answer for all clusters is "*strongly agree*", except for cluster 2 with high CO_2 footprint in mobility sector, where the first and the second dominant answers are "*moderately agree*" and "*Neither disagree nor agree*" which is a key outcome as it might directly correlate with the high CO_2 footprint in the mobility sector. Additionally, cluster 4 with high CO_2 footprint on housing has citizens with "*Neither disagree nor agree*" opinion about climate change as a majority.

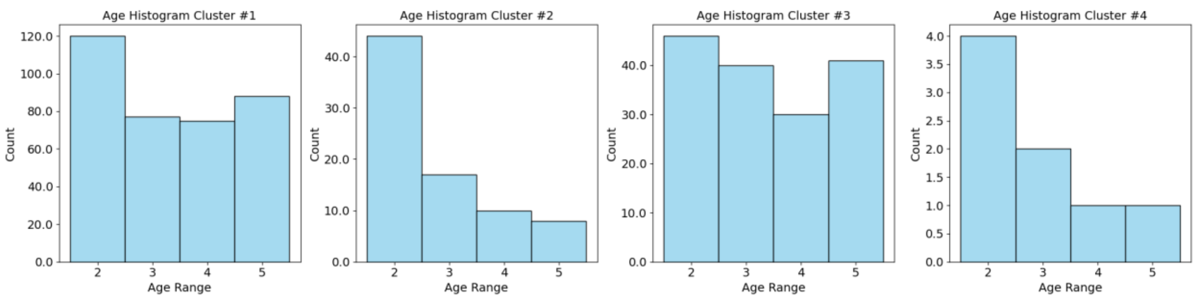

Figure 23 - "Within-cluster" statistics for age attribute in the Netherlands, x axis is citizens' answer about their age range. (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

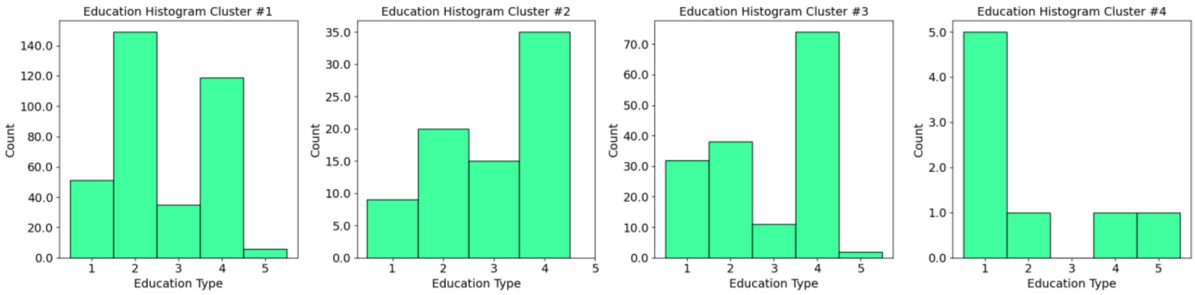

Figure 24 - "Within-cluster" statistics for education attribute in the Netherlands, x axis is citizens' answer about their education level (1: Elementary or secondary school, 2: Professional training, 3: A-Levels, 4: University or college degree, 5: Other) and y axis is population per answer.

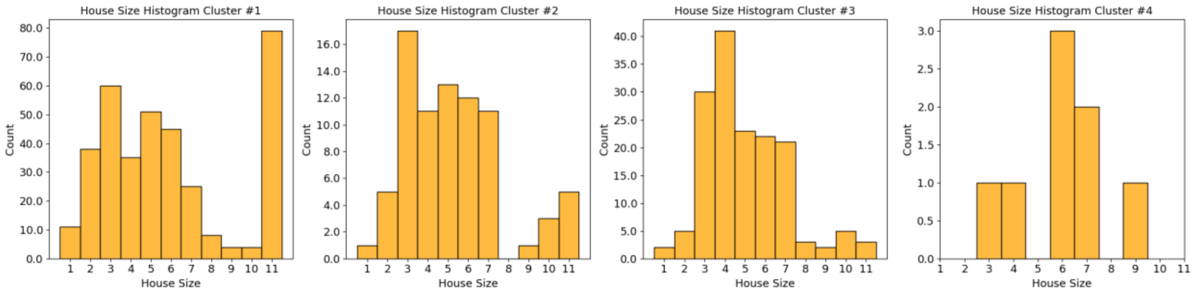

Figure 25 - "Within-cluster" statistics for house size attribute in the Netherlands, x axis is citizens' answer about their house size (m2) (1: <30, 2: 31-50, 3: 51-70, 4: 71-90, 5: 91-110, 6: 111-130, 7: 131-150, 8: 151-170, 9: 171-190, 10: >190, 11: I don't know (50 considered as average house size)) and y axis is population per answer.

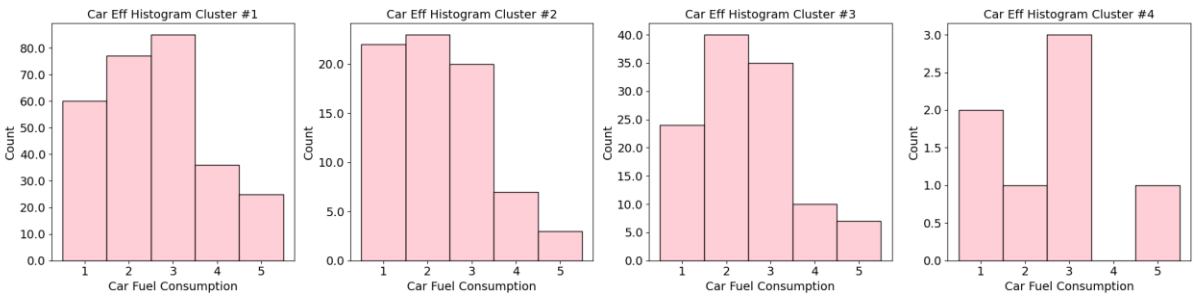

Figure 26 - "Within-cluster" statistics for car fuel efficiency attribute in the Netherlands, x axis is citizens' answer about their car fuel efficiency (litre/(100 km)) (1: 1-2, 2: 2-4, 3: 4-5, 4: 5-7, 5: >7, 6: E/V, 7: I don't know) and y axis is population per answer.

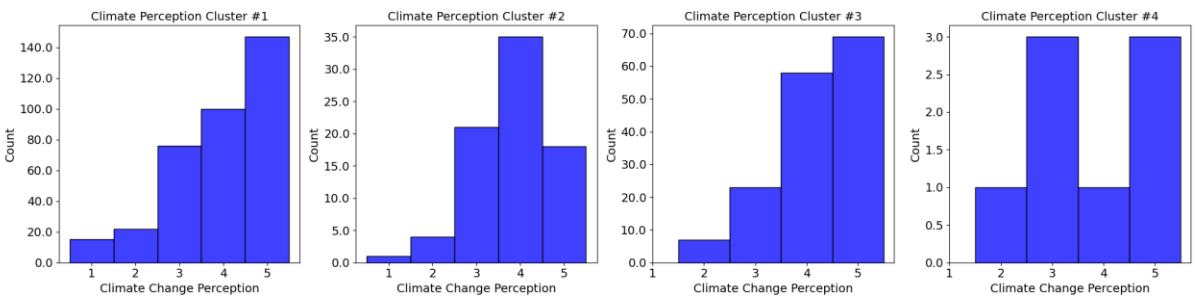

Figure 27 - Figure 18 - "Within cluster" statistics for climate change in the Netherlands, x axis is citizens' answer about their cli-mate change perception) (1: Strongly disagree, 2: Moderately disagree, 3: Neither disagree nor agree, 4: Moderately agree, 5: Strongly agree) and y axis is population per answer.

3 Energy citizen profile

At the core of the ENCLUDE project is the development of a deeper understanding of the concept of typology of energy citizenship for diverse communities of citizens (Dunphy et al., 2023) (ENCLUDE Project, 2024). This section aims to discover energy citizens' profiles based on the carbon footprint clustering (related to energy consumption) and within-cluster analyses for the selected countries, which were presented in the previous sections. Based on the within-cluster statistics, it is possible to identify citizens' profiles for each cluster or combinations of clusters.

3.1 UK

As presented in **Table 1**, three profiles have been derived. Clusters A and C (please refer to Figure 6 in D 4.2 (Naderian et al., 2024) are combined into profile #1, which mainly consists of citizens with low level of CO_2 footprint on housing and mobility. This profile represents 65% of the population, mostly young people with college degrees. The citizens in profile #2 represent 30% of the respondents and they are older than 65 years old with medium to high CO_2 footprint in the housing sector, but low CO_2 footprint in the mobility sector. Profile #3 represents 5% of the population, consuming more energy on mobility and with high level of CO_2 emissions on mobility. The infographic in **Figure 28** summarizes the three citizens profiles identified for the UK.

Table 1 - Profile results for CO2 footprint clustering based on within-cluster statistics for the UK

Attribute	Profile #1	Profile #2	Profile #3
Age range	19-34	>65	35-49
Education	College	College	College
Population %	64.95%	30.22%	4.82%
Energy on Mobility	Low	Low to medium	High
CO2 Emissions (housing and mobility)	Low	Medium to high	High
Climate Change Perception	positive	Neutral to positive	Neutral to positive

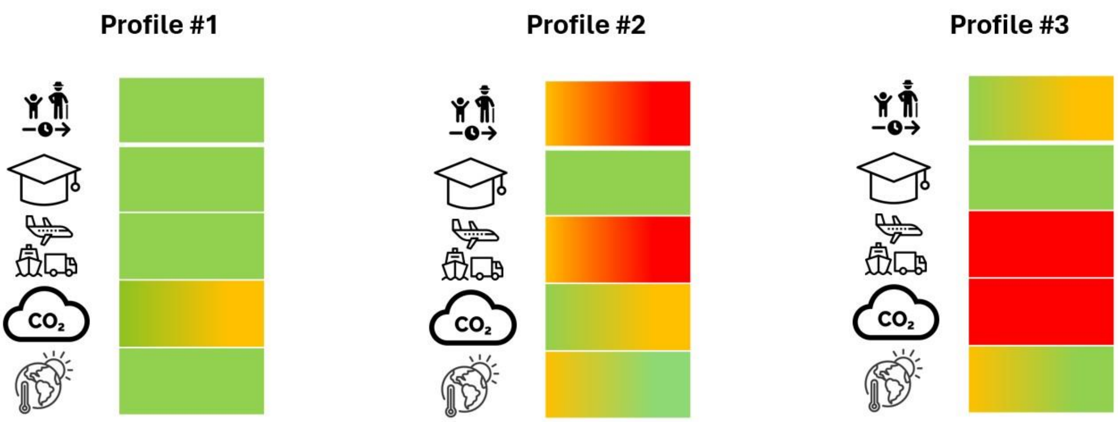

Figure 28 - Energy citizens profiles based on clustering results and within-cluster statistics for the UK.

3.2 Greece

Following the same approach shown above for the UK, three energy citizen profiles are defined for Greece based on within-cluster results, as presented in **Table 2.** In this case, each profile corresponds to one cluster. Profile #1 represents 73% of the population, mostly young people with college degrees and low CO_2 footprint on housing and mobility. Profile #2 represents 15% of the population, mostly middle-aged people with medium to high level of CO_2 footprint and neutral to positive opinion regarding climate change. The infographic in **Figure 29** summarizes the three citizens profiles identified for Greece.

Table 2 - Profile results for CO2 footprint clustering based on within-cluster statistics for Greece.

Attribute	Profile #1	Profile #2	Profile #3
Age range	19-34	19-34 and 35-49	19-34
Education	College	College	College
Population %	72.63%	14.92%	12.45%
Energy on Mobility	Low to Medium	Medium to High	Medium to High
CO2 Emission (housing and mobility)	Low	Medium to high	Low to Medium
Climate Change Perception	Positive	Neutral to positive	Positive

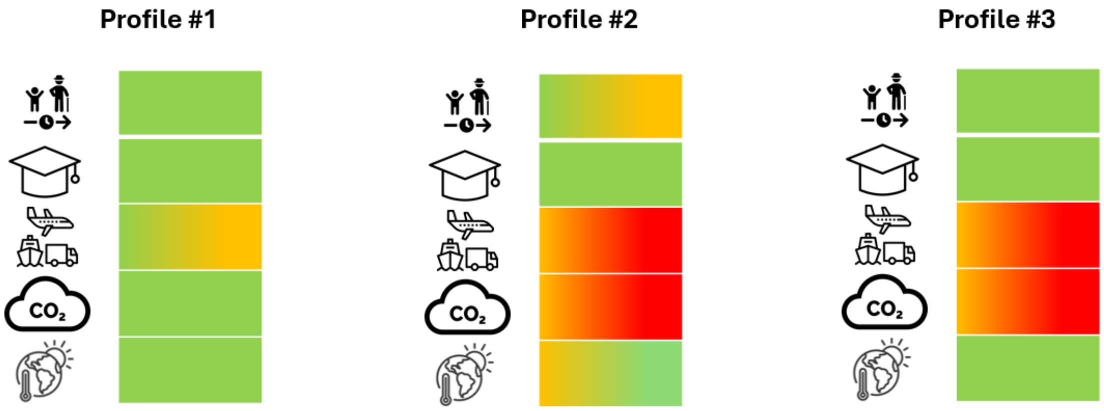

Figure 29 - Energy citizens profiles based on clustering results and within-cluster statistics for Greece.

3.3 The Netherlands

Based on the within-cluster analyses for the Netherlands, three energy citizens' profiles can be defined, as shown in **Table 3**. Profile #1 represents 40% of the population, consisting mainly of citizens with low level of CO_2 footprint on housing and mobility, mostly young and old people with college degrees. Profile #2 represents 19% of the population, with high energy consumption and CO_2 footprint in the mobility sector, who have neutral to positive opinion about climate change. Members of this profile are young people with college or professional degrees. Profile #3 is a combination of the citizens of cluster 3 and cluster 4, with medium to high CO_2 footprint on housing. They are mostly middle-aged people with college degree, and they also have neutral to positive opinion about climate change. The infographic in **Figure 30** presents the three citizens profiles identified for the Netherlands.

Table 3 - Profile results for CO2 footprint clustering based on within cluster statistics for the Netherlands

Attribute	Profile #1	Profile #2	Profile #3
Age range	19-34, >65	19-34	19-34,35-49
Education	Professional and College	College and Professional	College
Population %	39.60%	19.55%	40.84%
Energy on Mobility	Low to Medium	Medium to High	Low to Medium
CO2 Emission (housing and mobility)	Low	Medium to High	Low to Medium
Climate Change Perception	Positive	Neutral to Positive	Neutral to Positive

Figure 30 - Energy citizens profiles based on clustering results and within-cluster statistics for The Netherlands

4 ENCLUDE data set clustering and analysis

4.1 Index-based clustering

ENCLUDE studies energy citizenship from a collective ociological perspective, to understand the processes and factors of the emergence and consolidation of energy citizenship. It builds upon the framework of Energy Cultures (ENCLUDE Project, 2024) . WP3 carried out a survey in which information on demographic, cognition-related, energy consumption, and energy behavior aspects related to its participants were gathered. The target group for the questionnaire included participants in the collective energy action initiatives1 (Brenner-Fliesser et al., 2023). The dataset consists of data for 283 citizens around Europe, with the majority of the respondents from North Macedonia, Greece, and the Netherlands. The ENCLUDE data set consists of the categories “cognitive norms”, “energy practices”, and “material culture”, as presented in D3.1 (Brenner-Fliesser et al., 2023). Given the need for a sufficient amount of data for meaningful clustering, all ENCLUDE countries were considered for the analyses presented in this section.

All the gathered data are qualitative in nature, which makes it difficult to apply conventional clustering. Thus, a different approach was taken within WP4 to convert all answers into normalized numerical values and then calculate ‘indices’ for each category using simple addition of answers that are mapped to the numbers. To cluster the ENCLUDE data from D3.1, the following four categories were introduced, corresponding to four indices: Energy Poverty, Mobility, Housing, and Climate Change Perception. The following questions have been considered from the original ENCLUDE questionnaire. Some of them mention 'Reverse' before the question, indicating a reverse mapping of all the values for the answer to that question (i.e., the most positive answer is considered as the lowest value, e.g. 1 and vice versa). The list of the relevant questions associated to the introduced indices is shown below and summarized in **Table 4.**

Question set 1: Energy Poverty: Bigger value means more energy poverty

- “*poverty_A*” (Reverse)
  Have you ever had difficulties paying your bills for heating or electricity?
- “*poverty_B*”
  During last winter, did you perceive your home as comfortable in terms of temperature?
- “*poverty_C*”
  During last summer, did you perceive your home as comfortable in terms of temperature?

Question set 2: Energy on Mobility: Bigger value means more energy consumption

- “*materialculture_A*”
  Having a car is simply part of being an adult.
- “*materialculture_B*”
  Electric cars are no real alternative to fossil fueled cars.
- “*materialculture_C*”
  Public transport is no real alternative to driving your own car.

Question set 3: Energy on Housing: Bigger value means more energy consumption

- “*materialculture_D*”
  Heating with fossil fuels is a good energy solution.] Please indicate how much you agree or disagree with the following statements.
- “*materialculture_E*”
  A reliable supply of electricity to private households can only be provided by companies.
- “*materialculture_F*” (Reverse)

Investing in energy efficiency is beneficial for my household.]
- "*materialculture_G*" (Reverse)
Improving living conditions (e.g. thermal comfort) is as important for me as reducing energy consumption and bills.

Question set 4: Climate Change Perception: Bigger value means better perception

- "*clchangecause*"
Which do you think are the causes of the rising world temperature?
- "*pers0proenv*"
Acting pro-environmentally is an important part of who I am.

Table 4 - Considered questions for index-based clustering approach for ENCLUDE data set.

Index	Questions	Outcome
EPI: Energy Poverty Index	poverty_A, poverty_B, poverty_C	Higher value = Higher energy poverty
EMI: Energy on Mobility Index	materialculture_A, materialculture_B, materialculture_C	Higher value = Higher energy consumption
EHI: Energy on Housing Index	materialculture_D, materialculture_E, materialculture_F, materialculture_G	Higher value = Higher energy consumption
CPI: Climate Perception Index	Clchangecause, pers0proenv	Higher value = Better perception

4.2 Within-cluster analysis

All four indices have been calculated and assigned to each respondent then normalized to the range of 0-100 (0 = min, 100 = max). **Table 5** shows examples of respondents and calculated indices for each of the four categories. The k-means clustering method is applied to the full data set. Based on the elbow method (previously described in D4.2 (Naderian et al., 2024)), four clusters are identified. **Table 6** shows the results for each of the four clusters with its population and centroid. The spider plots in **Figure 31** represent the clustering results for each cluster based on the defined indices and the centroid of each index cluster.

In addition to the qualitative data discussed above, the ENCLUDE dataset gathered as part of D3.1 includes also a few sociodemographic data. Thus, within-cluster statistical analysis based on age, place of residency, education, and status of employment was carried out for the clusters identified in Table 6 for the defined indices. The findings are shown in **Figures 32-35**.

Cluster 1, which has the highest Energy Mobility Index, primarily consists of young people or people in their 50s and 60s living in villages who have completed secondary education. Cluster 2, which has the highest Climate Perception Index, is mostly composed of old people living in villages, who have completed tertiary education. Cluster 3, which has the highest Energy Poverty Index, consists predominantly of older individuals residing in villages. While most are still employed, a significant portion is retired. In contrast, Cluster 4, marked by the lowest Energy Mobility Index and one of the highest Climate Perception Index scores, is primarily made up of middle-aged, university-educated individuals living in large cities

Overall, all clusters except for cluster #1 have good climate perception. Cluster 1 results suggest a possible correlation between low energy poverty and medium to low climate change perception. Cluster 2 has high energy poverty while energy indices on housing and mobility are low, and climate perception is very high. Similar results on energy indices are observed for cluster 4, with a lower Energy Poverty Index.

Table 5 - Example of respondents and calculated indices for each category.

id	Energy Poverty Index	Energy Housing Index	Energy Mobility Index	Climate Perception Index
14	9	4	4	8
17	8	6	5	8
21	15	10	10	7
22	10	7	6	8
25	13	8	9	8
26	12	9	4	8

Table 6 - Clustering results based on defind indices for the ENCLUDE data set.

Cluster	Population	Energy Poverty Index	Energy Housing Index	Energy Mobility Index	Climate Perception Index
1	111	41.12	39.08	60.80	64.28
2	76	87.22	31.98	18.57	89.18
3	54	89.62	77.81	47.99	67.37
4	42	48.37	33.18	15.10	90.47

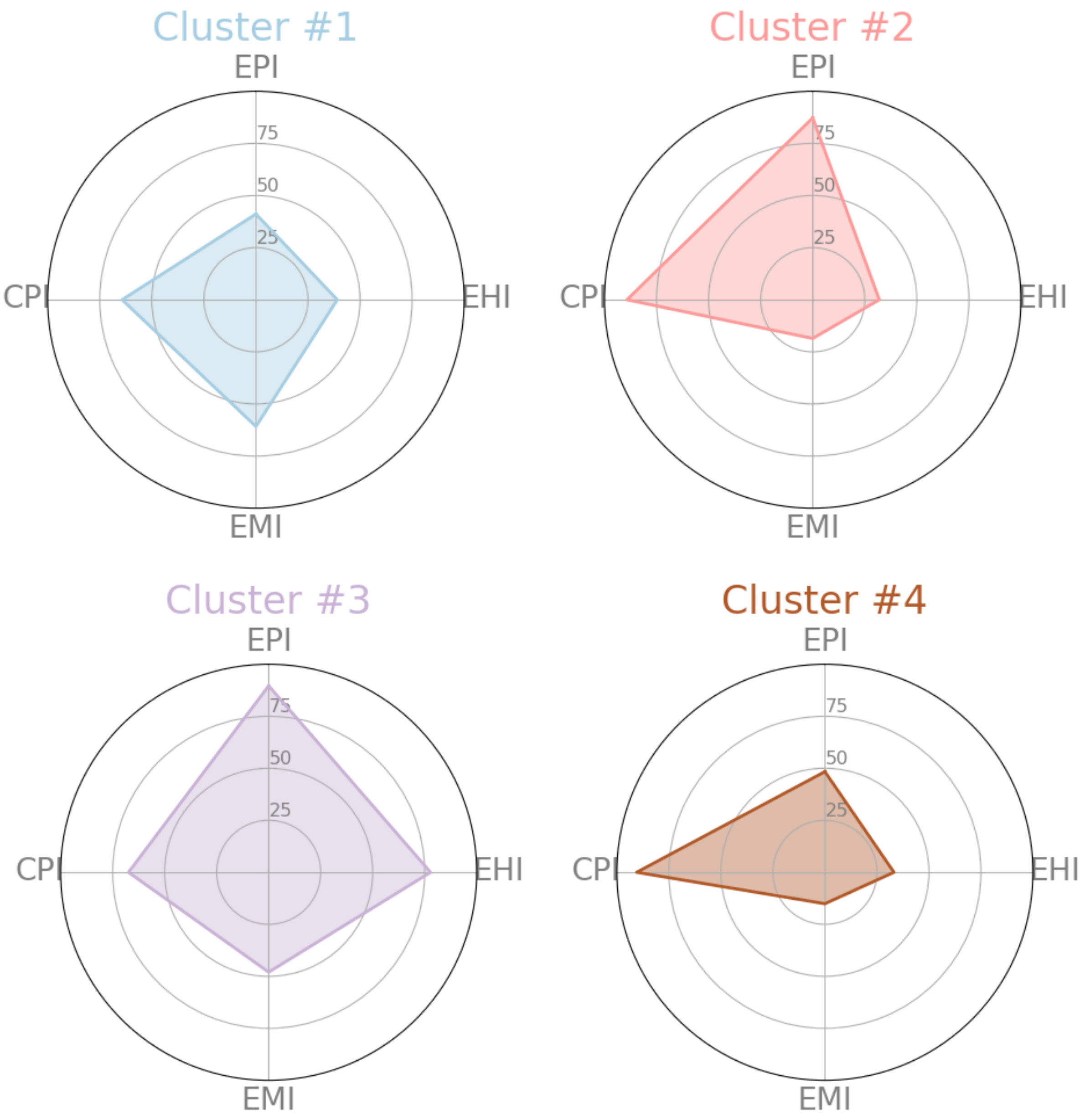

Figure 31 - Spider plots of index-based clustering results for each of four clusters.

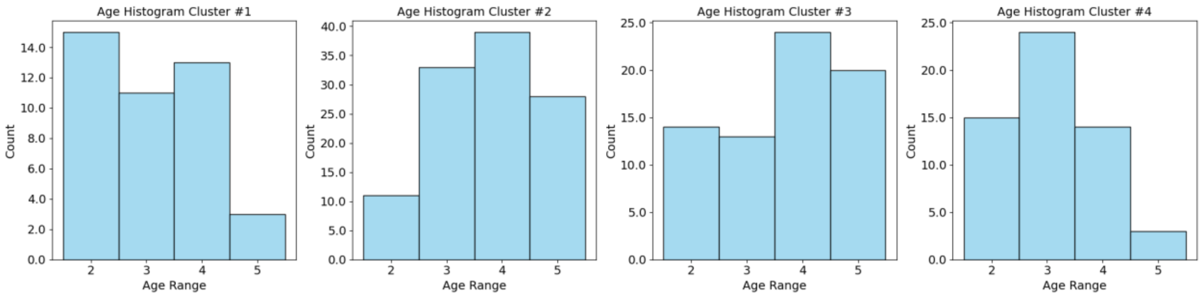

Figure 32 - “Within-cluster” statistics for age attribute for the ENCLUDE dataset, x axis is citizens’ answer about their age range. (2: 19-34 years old, 3: 35-49 years old, 4: 50-65 years old, 5: >65 years old) and y axis is population per answer.

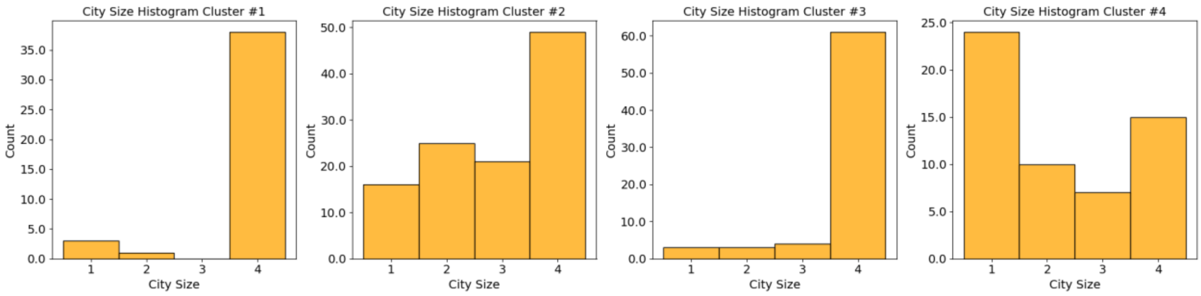

Figure 33 - “Within-cluster” statistics for city size attribute for the ENCLUDE dataset, x axis is citizens’ answer about their city size. (1: Large city 2: Small to medium city, 3: Medium town, 4: A village or small town) and y axis is population per answer.

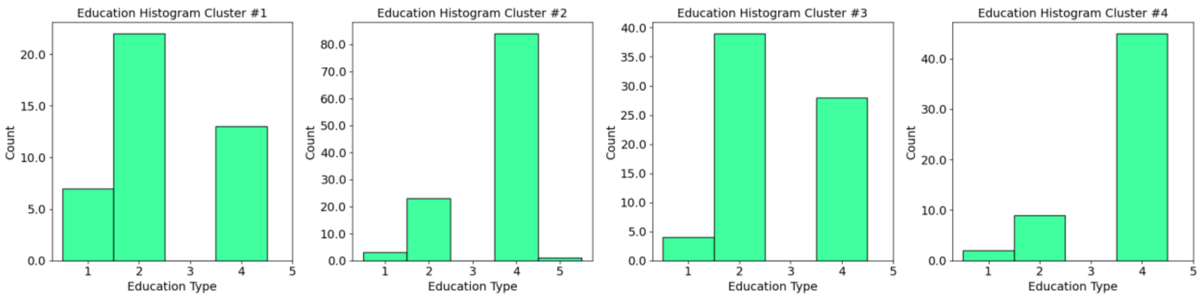

Figure 34 - “Within-cluster” statistics for education attribute for the ENCLUDE dataset, x axis is citizens’ answer about their education level (1: Primary education, 2: Secondary education, 4: Higher education, 5: I am still in education), and y axis is population per answer.

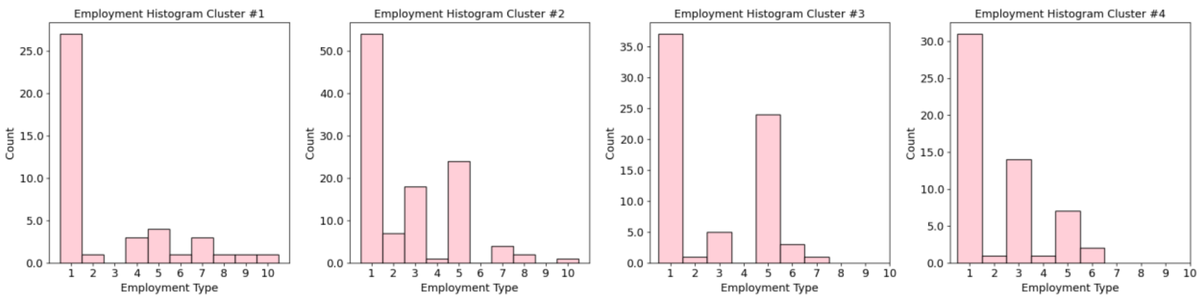

Figure 35 - “Within-cluster” statistics for employment attribute for the ENCLUDE dataset, x axis is citizens’ answer about their employment status (1: Paid employed (30 hours a week or more), 2: Paid employed (less than 30 hours a week), 3: Self-employed, 4: Non-continuous employment, 5: Retired/pensioned, 6: Not in paid employment and seeking paid employment, 7: Not in paid employment and not seeking paid employment, 8: Unpaid voluntary work, 9: Full time student, 10: Not able to work due to illness or disability), and y axis is population per answer.

5 Bridging energy citizens' profiles with energy models

The final step is to bridge the findings from the clustering analyses with the ENCLUDE work on energy modeling, so as to facilitate the translation of the outputs of the clusters' characteristics to inputs of the energy models. In this way, the decarbonization potential of the identified groups of citizens can be quantified by the energy models.

This will effectively be realized through the translation of the clusters' characteristics, including energy behaviors and carbon emissions, along with the relevant contextual factors, into inputs to the energy models and carbon neutral scenarios. This bridging serves the purpose of facilitating the estimation of the aggregated decarbonization impact of strategic groups of energy citizens.

D5.3 (Fotopoulos et al., 2024) aimed to model the decarbonization impact of energy citizenship at the micro scale and local level (i.e., household, community, municipality). They upscaled modeling outcomes and by enhancing the ENCLUDE modeling ensemble accordingly, they employed it to extract insights regarding the decarbonization potential of different manifestations of energy citizenship at the macro scale (i.e., national and supranational - European Union - level) (Manias et. al, 2024)Click or tap here to enter text.. To simulate the different transition pathways that were derived from the ENCLUDE transformative scenario design framework, three models were employed: ATOM (Agent-based Technology adOption Model), IMAGE (Integrated Model to Assess the Global Environment), and OSeMOSYS-GR (Open-Source energy MOdeling SYStem for GReece) (Manias et. al, 2024)Click or tap here to enter text..

Set to explore the decarbonization potential of different expressions of energy citizenship as manifested at the national and the international levels, D5.4 focused on all four "people-centered" storylines, namely: (i). "Power to the People", (ii). "Habitual Creatures", (iii). "Band Together", and (iv). "People to the Streets" (Manias et al., 2024). Each of these scenarios was developed based on specific characteristics of the citizens and percentage of their participation in energy initiatives, with the aim to project decarbonization pathways by 2030 and 2050.

The clustering results, within-cluster analysis and citizens' profile development shown in D4.2 and in this report could be beneficial to refine and tailor energy models, as they mostly consider synthetic data or data that are not of sufficient country/community-scale granularity for scenario development. Based on the energy citizens' profiles presented in this report, decarbonization scenarios could be tailored according to the age, education, energy consumption and climate change perspective of the citizens for the countries analyzed.

Specifically, as part of Deliverable 5.5, the clustering results from Deliverable 4.2 and the profiling outcomes from this report will be integrated in the energy system modeling simulations, by translating the clusters' characteristics and energy behaviors into inputs for the ENCLUDE modeling ensemble. This integration will enable the quantification of the decarbonization potential of different energy citizen groups, demonstrating which clusters are more significant and responsive towards accelerating decarbonization efforts.

The series of analyses presented in this report aims to represent a systematic framework for future application to more countries and/or new data sets, with the opportunity to bridge energy citizen clusters and profiles to energy models at different scales (from community to district, city, national and supranational).

6 Summary and conclusions

This deliverable is part of the ENCLUDE project, which aims to promote energy citizenship and sustainable practices across the EU. The specific objective of D4.3 was to bridge clusters of citizens based on their energy consumption patterns and carbon footprint for decarbonization with energy models.

Starting from the clustering results of citizens based on their energy consumption and CO_2 footprint (from D4.2 (Naderian et al., 2024)), this deliverable first provides within-cluster analysis for the UK, Greece, and the Netherlands, examining each country based on sociodemographic, energy consumption, and psychological attributes.

Based on the within-cluster analysis, citizens of the selected countries are found to be mostly consuming low to medium energy in both mobility and housing sectors. From an age and education perspective, they are mostly young people with college or university degree. They tend to live in small houses and own cars with low fuel consumption. They also have a positive attitude towards the urgency of global warming. A minority of citizens for the selected countries show high energy consumption on either mobility or housing. This group of citizens are middle-aged or old people, and own cars with higher fuel consumption or live in bigger houses. Additionally, they have neutral to positive climate change perception.

According to the results of the within-cluster analysis, three profiles were defined for the selected countries that classify citizens based on five attributes: age, education, energy consumption, CO_2 footprint on mobility, and climate change perception. This approach creates an opportunity to compare selected countries and measure the population of each profile, and to tailor energy models based on the profiles.

This deliverable then shows clustering results and within-cluster analysis for the citizens of the ENCLUDE dataset, which was gathered as part of D3.1. This data set includes citizens who have participated in energy initiatives in Europe. Due to the qualitative nature of the ENCLUDE data set, an index-based clustering approach was developed in WP4 to assess the emergence of categories of citizens. Four clusters were identified, corresponding to four indices: Energy Poverty Index, Energy Housing Index, Energy Mobility Index, and Climate Perception Index. A within-cluster analysis was carried out for each of four clusters to extract relevant citizens' profiles to inform energy models. The within-cluster results shown in this deliverable suggest a possible correlation between low energy poverty and medium to low climate change perception.

In summary, this deliverable presents a data-driven approach to group citizens based on mixed (qualitative and quantitative) information of energy consumption, carbon footprint, sociodemographic factors, and perception of climate change. This approach can prove valuable to the development of scenarios for energy models to identify different decarbonization pathways towards a just energy transition.

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