A CONCEPTUAL FRAMEWORK OF INFORMATION VISUALIZATION MEASURES: IDENTIFYING KEY EVALUATION CRITERIA FOR CLIMATE CHANGE VISUALS

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A CONCEPTUAL FRAMEWORK OF INFORMATION VISUALIZATION MEASURES: IDENTIFYING KEY EVALUATION CRITERIA FOR CLIMATE CHANGE VISUALS

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DECLARATION OF ORIGINALITY

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ABSTRACT

There is a challenge to deliver effective designs on the climate crisis due to the complexity of the issue and the large volume of scientific data involved. To overcome this challenge, information visualizations are designed to help communicate complex data. Information visualizations, being data-driven, necessitate considering specific measures in addition to fundamental graphic design principles. This study investigates the communication of climate change through information visualizations, with the aim of determining the prominent measures and their interrelations within climate change context. In the preliminary study, exploratory interviews were conducted with expert designers to have an overall view on the use of measures in information visualization. In the second stage, five workshops were conducted with academics, design professionals and NGOs. Finally, to examine the relationship between the identified information visualization measures and the overarching goals of climate change communication, a survey was conducted with expert designers. A conceptual framework of measures is suggested where context specific measures such as *actionability*, *enlightening capability*, *evoking curiosity, evoking emotions, localization, personalization* and *positivity* are highlighted as measures in designing effective climate change visualizations. This study contributes to the fields of information visualization and communication design by offering a conceptual framework for information visualization measures for the context of climate change.

Keywords: Climate change communication, information visualization, information visualization measures, data visualization

ÖZET

İklim krizi, konunun karmaşıklığı ve içerdiği büyük hacimli bilimsel veri nedeniyle etkili tasarımlar oluşturmayı zorlaştırmaktadır. Bu zorluğun üstesinden gelmek için, karmaşık verilerin iletişimini kolaylaştırmak amacıyla bilgi görselleştirmeleri tasarlanmaktadır. Veri odaklı olan bilgi görselleştirmeleri, temel grafik tasarım prensiplerine ek olarak belirli ölçütlerin de dikkate alınmasını gerektirmektedir. Bu çalışma, bilgi görselleştirmeleri aracılığıyla iklim değişikliği iletişimini araştırmakta ve iklim değişikliği bağlamında öne çıkan ölçütleri ve bunların birbiriyle ilişkilerini belirlemeyi amaçlamaktadır. Çalışmanın ilk aşamasında, bilgi görselleştirmelerinde ölçütlerin kullanımıyla ilgili genel bir bakış elde etmek amacıyla uzman tasarımcılarla keşif görüşmeleri gerçekleştirilmiştir. İkinci aşamada, akademisyenler, tasarım profesyonelleri ve STK'larla beş çalıştay yapılmıştır. Son olarak, belirlenen bilgi görselleştirme ölçütleri ile iklim değişikliği iletişiminin genel hedefleri arasındaki ilişkiyi incelemek amacıyla uzman tasarımcılarla bir anket çalışması yürütüldü. Çalışma sonucunda, etkin iklim değişikliği görselleştirmeleri tasarlamak için *eyleme geçirilebilirlik*, *aydınlatıcılık*, *merak uyandırma*, *duyguları harekete geçirme*, *yerelleştirme*, *kişiselleştirme* ve *pozitiflik* gibi bağlama özgü ölçütlerin vurgulandığı bir kavramsal ölçüt çerçevesi önerilmiştir. Bu çalışma, iklim değişikliği bağlamında bilgi görselleştirme ölçütleri için bir kavramsal çerçeve sunarak bilgi görselleştirme ve iletişim tasarımı alanlarına katkı sağlamaktadır.

Anahtar Kelimeler: İklim değişikliği iletişimi, bilgi görselleştirme, bilgi görselleştirme ölçütleri, veri görselleştirme

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TABLE OF CONTENTS

DECLARATION OF ORIGINALITY iii
ABSTRACT iv
ÖZET v
ACKNOWLEDGMENTS vi
LIST OF TABLES xi
LIST OF FIGURES xii
LIST OF ACRONYMS AND ABBREVIATIONS xix
1. INTRODUCTION 1
1.1 Aim of the Study 3
1.2 Research Questions 3
1.3 Dissertation Outline 4
2. BACKGROUND: FUNDAMENTALS OF INFORMATION VISUALIZATION AND CLIMATE CHANGE COMMUNICATION 8
2.1 Defining Information Visualization 8
2.1.1 Information Visualization as a Field 10
2.1.2 Brief History of Information Visualization 12
2.1.3 Types of Information Visualizations 17
2.1.3.1 Charts for Comparison 18
2.1.3.2 Charts for Correlation 24
2.1.3.3 Charts for Distribution 26
2.1.3.4 Charts for Geolocation 28
2.1.3.5 Charts for Part-to-Whole 31
2.1.3.6 Charts for Trend Over Time 34
2.2 Climate Change Communication 36
2.2.1 Climate Change Audience Segmentation 38
2.2.2 Public Perceptions of Climate Change in Turkey 39
2.2.3 Evolution of Climate Change Communication Approaches 40
2.2.4 Public Engagement and Localized Communication Strategies 42
2.2.5 Emotional and Motivational Dimensions of Climate Communication 43

2.2.6 Barriers to Effective Climate Communication: Complexity and Uncertainty... 44
2.2.7 Bridging the Science–Public Gap: The Need for Intermediaries and Clarity 46
2.2.8 Role of Information Design and Visualization in Climate Communication.. 47
2.2.9 Principles and Best Practices for Effective Climate Change Communication .. 49
2.2.10 Trust and Communicator Credibility 50
2.2.11 Climate Communication Initiatives, Public Awareness and Green PR in Turkey 51
2.2.12 Traditional Media vs. New Media in Climate Communication..... 54
2.2.13 Social Media and User-Generated Content: Potential and Challenges..... 58
2.2.14 Summary of Chapter 61
3. METHODOLOGY 63
3.1 First Stage: Exploratory Interviews with Experts 63
3.2 Second Stage: Workshops with Experts 67
3.2.1 Workshop Participant Selection..... 68
3.2.2 Workshop Protocol 70
3.2.3 Materials: Information Visualization Examples 72
3.2.4 Analysis..... 73
3.3 Third Stage: Survey with Experts and the Conceptual Framework..... 75
3.3.1 Survey Structure and Design 77
3.3.2 Participants of the Survey 78
3.3.3 Analysis of the Survey 80
3.3.4 Towards a Conceptual Framework 81
4. MEASURES IN INFORMATION VISUALIZATION 84
4.1 Perception and Cognition-Oriented Measures 88
4.1.1 Comprehension 89
4.1.1.1 Levels of Comprehension 89
4.1.1.2 Factors Affecting Comprehension 91
4.1.2 Memorability..... 93
4.1.2.1 Images and Memorability 95
4.1.2.2 Other Factors that Affect Memorability 96

4.1.3 Clarity 98
4.1.4 Saliency 101
4.2 Task-Oriented Measures 102
4.2.1 Accuracy 103
4.2.2 Speed 105
4.3 Affect-Oriented Measures 108
4.3.1 Credibility 108
4.3.1.1 Trust in Data and Source 109
4.3.1.2 Trust and Design Elements 110
4.3.2 Engagement 112
4.3.2.1 Defining Engagement 112
4.3.2.2 Importance of Engagement 114
4.3.2.3 Evaluating and Measuring Engagement 115
4.3.2.4 Various Factors Studied for Assessing Engagement 115
4.3.3 Aesthetics 118
4.3.3.1 Factors that Affect Aesthetics 119
4.3.3.2 Impact of Aesthetics 122
4.3.4 Enjoyment 123
4.4 Goal-Oriented Measures 124
4.4.1 Actionability 124
4.4.2 Personalization 127
4.5 Usability-based Measures 128
4.5.1 Efficiency 128
4.5.2 Utility 130
4.6 Relationship Between Measures and Context Dependency 130
5. PRELIMINARY STUDY 133
5.1 Findings of the Preliminary Study 133
5.2 Conclusions of the Preliminary Study 136
6. FINDINGS AND RESULTS OF WORKSHOPS AND SURVEY 138
6.1 Findings of Workshops 1-5 138
6.1.1 Actionability 140
6.1.2 Enlightening 143

6.1.3 Evoking Curiosity 148
6.1.4 Evoking Emotions 149
6.1.5 Localization 151
6.1.6 Personalization 153
6.1.7 Positivity 156
6.1.8 Storytelling 157
6.1.9 Clarity 158
6.1.10 Credibility 159
6.1.11 Engagement 161
6.1.12 Saliency 164
6.1.13 Graphic Designers vs. NGOs 164
6.2 Results: Towards a Conceptual Framework 166
6.2.1 Measures for Goal 1: Building Trust Through Reliable Information 167
6.2.2 Measures for Goal 2: Clear, Inclusive, and Solution-Oriented Communication 169
6.2.3 Measures for Goal 3: Encouraging Action with Urgency and Hope 172
6.2.4 On the Overall Effectiveness of Measures 175
6.2.5 Cross-Goal Synthesis and Overall Critical Measures 177
7. CONCLUSION 181
REFERENCES 185
APPENDICES 214
APPENDIX A. FIRST LEVEL CODES, SECOND LEVEL CODES AND THEMES FROM PRELIMINARY STUDY 215
APPENDIX B. IMAGES FROM THE CONDUCTED WORKSHOPS 235
APPENDIX C. VISUAL MATERIALS USED IN WORKSHOPS 239
APPENDIX D. SURVEY STRUCTURE AND DESIGN 291
APPENDIX E. FIRST LEVEL OF CODES IN WORKSHOPS 1-5 303
APPENDIX F. GLOSSARY 329
APPENDIX G. CURRICULUM VITAE 333

LIST OF TABLES

Table 3.1 Interview Questions for Part 1 64
Table 3.2 Images Shown in Part 2 of the Exploratory Interview 65
Table 3.3 Table Used to Collect Ratings and Notes in Part 2 66
Table 3.4 Participants of the Workshop 1 68
Table 3.5 Workshop Protocol 71
Table 4.1 Various Measures Found in Literature 87
Table 4.2 Engagement Described by Mahyar et al. (2016), Amini et al., (2018), Hung and Parsons (2017) and Kennedy et al. (2016) 114
Table 5.1 The Table Shows the Answers for Questions 7 and 8 of the Interview 136
Table A.1 Participant Ratings and Comments for First Information Visualization 223
Table A.2 Participant Ratings and Comments for Second Information Visualization 225
Table A.3 Participant Ratings and Comments for Third Information Visualization ... 227
Table A.4 Participant Ratings and Comments for Fourth Information Visualization . 229
Table A.5 Participant Ratings and Comments for Fifth Information Visualization 231
Table A.6 Participant Ratings and Comments for Sixth Information Visualization.... 233

LIST OF FIGURES

Figure 2.1 The DIKW Pyramid Inspired from Kirill Soloviev's Depiction..... 10
Figure 2.2 Timeline Showing Eras of Information Visualization, Based on Friendly and Wainer's Timeline (2021, p. 4)..... 13
Figure 2.3 Van Langren's 1644 Graph Showing Measured Distances from Toledo to Rome..... 14
Figure 2.4 Graph, Diagram and Table..... 18
Figure 2.5 Types of Bar Charts..... 20
Figure 2.6 Lollipop Chart, Bullet Chart and Dot Plot..... 21
Figure 2.7 Pictogram Chart, Icon Chart and Range Plot..... 22
Figure 2.8 Parallel Coordinates, Nightingale Chart, Waterfall Chart and Matrix Chart 23
Figure 2.9 Small Multiples, Word Cloud, Alluvial Diagram, Chernoff Faces..... 24
Figure 2.10 Scatter Plot, Bubble Chart and Heatmap..... 26
Figure 2.11 Histogram and Box Plot..... 27
Figure 2.12 Density Plot and Violin Plot..... 28
Figure 2.13 Dot Density Map, Flow Map and Choropleth Map Showing Number of People Per House by Turkish Institute of Statistics (2021)..... 30
Figure 2.14 Johns Hopkins Dashboard Showing Global Covid-19 Statistics..... 31
Figure 2.15 Different Types of Pie and Donut Charts..... 32
Figure 2.16 Treemap and Sunburst Chart..... 34
Figure 2.17 Line Chart and Area Chart..... 35
Figure 2.18 The Percentages of Six Types of Audience in Turkey..... 40
Figure 3.1 Areas of Expertise of Survey Participants..... 79
Figure 3.2 Years of Experience and Climate Change Experience of Survey Participants..... 80
Figure 6.1 Analysis Process Second Level Codes..... 139
Figure 6.2 Themes Derived in Analysis..... 140
Figure 6.3 The Countries that Pollute the Oceans the Most with Plastic Wastes..... 147
Figure 6.4 Oceans Are Warming: Global Ocean Surface Temperatures Between 1880-2019..... 149

Figure 6.5 63% of Us Associate the Increase in Unusual Seasonal Events with the Climate Crisis 152
Figure 6.6 How Much Does Your Food Cost the Planet? 155
Figure 6.7 Installed Wind Energy Capacity Per Year 157
Figure 6.8 How Do Extreme Heat Events Affect the Human Body? 162
Figure 6.9 The False Spring Delusion of Bees 163
Figure 6.10 Likert-Scale Results Chart for Goal 1 168
Figure 6.11 Indispensable Measures Selected for Goal 1 169
Figure 6.12 Likert-Scale Results Chart for Goal 2 171
Figure 6.13 Indispensable Measures Selected for Goal 2 172
Figure 6.14 Likert-Scale Results Chart for Goal 173
Figure 6.15 Indispensable Measures Selected for Goal 3 175
Figure 6.16 Overall Ranking of Measures for Effective Climate Change Communication 176
Figure 6.17 Survey Results and Themes from the Workshops 179
Figure A.1 Design Elements First and Second Level Codes 215
Figure A.2 Design Elements First and Second Level Codes Continued 216
Figure A.3 Design Principles First and Second Level Codes 217
Figure A.4 Measures First and Second Level Codes 218
Figure A.5 Measures First and Second Level Codes Continued 219
Figure A.6 Design Language and Narrative First and Second Level Codes 220
Figure A.7 Design Decision and Aim First and Second Level Codes 221
Figure A.8 Data Layers, Systematic and Design Rules First and Second Level Codes 222
Figure A.9 First Information Visualization Presented in Preliminary Study 223
Figure A.10 Second Information Visualization Presented in Preliminary Study 225
Figure A.11 Third Information Visualization Presented in Preliminary Study 227
Figure A.12 Fourth Information Visualization Presented in Preliminary Study 229
Figure A.13 Fifth Information Visualization Presented in Preliminary Study 231
Figure A.14 Sixth Information Visualization Presented in Preliminary Study 233
Figure B.1 Session 1 of Workshop 1 235
Figure B.2 Session 2 of Workshop 1 235

Figure B.3 Session 3 of Workshop 1 236
Figure B.4 Session 3 of Workshop 1 Continued..... 236
Figure B.5 Image from the Conducted Workshop 2 237
Figure B.6 Image from the Conducted Workshop 3 237
Figure B.7 Image from the Conducted Workshop 4 238
Figure B.8 Image from the Conducted Workshop 5 238
Figure C.1 Projected Average Temperature for 2100 239
Figure C.2 Installed Capacity of Wind Energy by Years 239
Figure C.3 The 2010s Were the Hottest Decade 240
Figure C.4 Distribution of Storms Experienced Throughout Turkey by Year 240
Figure C.5 Comparison of Average Temperatures in 2022..... 241
Figure C.6 Temperature Rise Since 1850..... 241
Figure C.7 Comparison of Water Basins in Turkey 242
Figure C.8 Turkey Annual Mean Temperature Anomaly Change Range 242
Figure C.9 The Most Signed Climate Campaigns in 2022 243
Figure C.10 The Most Carbon Dioxide Emitting Countries..... 243
Figure C.11 How Heat Waves Affect Human Body 244
Figure C.12 Every Year Is a Candidate for the Hottest Year 244
Figure C.13 The Effect of Climate Change on Weather Sourced Natural Disasters... 245
Figure C.14 EU Carbon Emissions by Country..... 245
Figure C.15 Heat Stress Alert for Nearly 900 million Farmers..... 246
Figure C.16 Which Countries Does the EU Send Its Garbage to 246
Figure C.17 Which Country Pollutes the World to What Extent 247
Figure C.18 66% of the Public in Turkey Is Anxious Because of Climate Crisis..... 247
Figure C.19 Future Temperature Predictions 248
Figure C.20 Environmental Disasters Caused by Humans..... 248
Figure C.21 Climate Change Cost EU 145 billion Euros in the Last Decade 249
Figure C.22 Yearly Carbon Emissions per Person 249
Figure C.23 3 Out of 4 People in Turkey Think Climate Crisis Cause Extreme Weather Events..... 250
Figure C.24 How Bad Will the Problem Get..... 250
Figure C.25 Increase Rate of Carbon Emissions of China by Years..... 251

Figure C.26 Which Countries Do EU Countries Send Their Waste to 251
Figure C.27 Effects of Sectors on Global Warming 252
Figure C.28 End-of-Month Reservoir Fill Rates Over the Past Year 252
Figure C.29 Plastic Waste Exports by Years 253
Figure C.30 Distribution of Carbon Emissions of the Richest 1% by Country 253
Figure C.31 Annual Greenhouse Gas Emissions by Sector 254
Figure C.32 Countries Emitting the Most Carbon 254
Figure C.33 Climate Change of Turkey 255
Figure C.34 The Earth Is Warming 255
Figure C.35 Shares of Primary Energy Resources in Production 256
Figure C.36 Greenhouse Gas and CO2 Emissions 256
Figure C.37 Annual Areal Precipitation in Turkey 257
Figure C.38 Turkey's Energy Saving Performance 257
Figure C.39 Carbon Emissions per Kilograms of Food Products 258
Figure C.40 Environmental Awareness in Turkey 258
Figure C.41 Every Decade Is Warmer Than the Previous One 259
Figure C.42 Do You Think Irregular Weather Conditions Increased Recently 259
Figure C.43 Global Carbon Emissions Approach Pre-Pandemic Levels 260
Figure C.44 Climate Situation in Turkey 260
Figure C.45 The Most Carbon-Emitting Countries 261
Figure C.46 Rate of Decline of Biodiversity by Region 261
Figure C.47 Oceans Are Warming 262
Figure C.48 Global Energy Consumption by Fuel Type 262
Figure C.49 Countries to Which the EU Exports Its Waste 263
Figure C.50 European Countries That Produce the Most Waste 263
Figure C.51 Countries that Dump Most Plastic Waste into Oceans 264
Figure C.52 Wind Power Capacity by Country 264
Figure C.53 Countries That Pollute Oceans the Most with Plastic Waste 265
Figure C.54 Three-Month Drought Map 265
Figure C.55 Methane Emissions 266
Figure C.56 Environmental Impacts of Milk by Type 266
Figure C.57 How Much Does Your Food Cost the World 267

Figure C.58 The Amount of Greenhouse Gas Emissions Saved by Person 267
Figure C.59 Top-10 Countries Experiencing Significant Tropical Forest Loss in 2021 268
Figure C.60 Humanity's Ecological Footprint Based on Land Use and Activities 268
Figure C.61 Global Methane Emissions 269
Figure C.62 Carbon Dioxide Equivalent Amount 269
Figure C.63 For 1 Liter of Milk 1000 Liters of Water Is Used 270
Figure C.64 For What Purposes Do We Use Water Most in Our Home 270
Figure C.65 June Was the Hottest Month 271
Figure C.66 Fire Season Average Danger Rates 271
Figure C.67 Warming Stripes 272
Figure C.68 Who Finances Fossil Fuels 272
Figure C.69 70% of Turkish Society Is Concerned About Climate Change 273
Figure C.70 August 2023 Temperature Comparison 273
Figure C.71 Three-Month Drought Map 274
Figure C.72 Greenhouse Gasses Emitted per 100 Grams of Protein Produced 274
Figure C.73 10 Commonly Consumed Foods That Are Harmful to Climate 275
Figure C.74 According to 47% of Us Difficulty in Access to Water Is Related to Climate Crisis 275
Figure C.75 63 % of Us Relate Extreme Weather Events with Climate Crisis 276
Figure C.76 How Many Worlds Would Be Needed If We All Lived as These Countries 276
Figure C.77 Hottest Month Ever 277
Figure C.78 What the People Think Climate Change Affects 277
Figure C.79 Standardized Precipitation Index 278
Figure C.80 Meat Consumption Causes More Greenhouse Gas Emissions 278
Figure C.81 Negative Effects of Consuming Too Much Meat 279
Figure C.82 The World Is Getting Warmer 279
Figure C.83 17 thousand Species Are in Danger 280
Figure C.84 How Close Is the World to the 1.5 Degree Global Warming Limit 280
Figure C.85 Climate Crisis in Developed Countries 281
Figure C.86 Sea Water Temperature in Turkey Are Rising 281

Figure C.87 Record Temperature on July 26 282
Figure C.88 Do You Take Your Shopping Bag With You to the Market 282
Figure C.89 Leading Roles in Plastic Pollution in Oceans and Rivers 283
Figure C.90 The Second Driest Winter in the Last 63 Years 283
Figure C.91 Zero Waste Day 284
Figure C.92 Wildfires in Turkey 284
Figure C.93 The Last 5 Years of Extreme Weather Events 285
Figure C.94 Meteorological Disaster in 2022 285
Figure C.95 False Spring Delusion of Bees 286
Figure C.96 How Much Water Is Used in Production 286
Figure C.97 Reservoirs of Istanbul at a Dangerous Level 287
Figure C.98 Annual Rainfall Amounts Measured in Dams 287
Figure C.99 Results of Packaging and Packaging Waste Released in 2020 288
Figure C.100 Which Two Power Plants Do You Prefer the Most 288
Figure C.101 Which Two Power Plants Do You Oppose the Most 289
Figure C.102 What Should Turkey Do Against Climate Change 289
Figure C.103 What Do You Think Is the Cause of Wildfires in Our Country 290
Figure C.104 Carbon Footprint of Food 290
Figure E.1 Workshop 1 First Level Codes 1 303
Figure E.2 Workshop 1 First Level Codes 2 304
Figure E.3 Workshop 2 First Level Codes 1 305
Figure E.4 Workshop 2 First Level Codes 2 306
Figure E.5 Workshop 2 First Level Codes 3 307
Figure E.6 Workshop 2 First Level Codes 4 308
Figure E.7 Workshop 2 First Level Codes 5 309
Figure E.8 Workshop 3 First Level Codes 1 310
Figure E.9 Workshop 3 First Level Codes 2 311
Figure E.10 Workshop 3 First Level Codes 3 312
Figure E.11 Workshop 3 First Level Codes 4 313
Figure E.12 Workshop 3 First Level Codes 5 314
Figure E.13 Workshop 3 First Level Codes 6 315
Figure E.14 Workshop 4 First Level Codes 1 316

Figure E.15 Workshop 4 First Level Codes 2 317
Figure E.16 Workshop 4 First Level Codes 3 318
Figure E.17 Workshop 4 First Level Codes 4 319
Figure E.18 Workshop 4 First Level Codes 5 320
Figure E.19 Workshop 4 First Level Codes 6 321
Figure E.20 Workshop 5 First Level Codes 1 322
Figure E.21 Workshop 5 First Level Codes 2 323
Figure E.22 Workshop 5 First Level Codes 3 324
Figure E.23 Workshop 5 First Level Codes 4 325
Figure E.24 Workshop 5 First Level Codes 5 326
Figure E.25 Workshop 5 First Level Codes 6 327
Figure E.26 Workshop 5 First Level Codes 7 328

LIST OF ACRONYMS AND ABBREVIATIONS

ACM: Association for Computing Machinery

HCI: Human Computer Interaction

IEEE: Institute of Electrical and Electronics Engineers

IPCC: Intergovernmental Panel on Climate Change

NGO: Non-Governmental Organizations

PR: Public Relations

UGC: User generated content

W1: Workshop 1

W2: Workshop 2

W3: Workshop 3

W4: Workshop 4

W5: Workshop 5

1. INTRODUCTION

Information visualizations are purposeful designs created to help communicate specific data in a specific way to viewers/audiences. Information visualizations are "more than just creative interesting images, they enhance decision-making and cognitive processes" (Card, 2012, p. 539). They help the viewer to see and discover the patterns and associations within the structure of data. In this way, information visualizations enable lay people and/or researchers to comprehend social, political, historical and economic processes through revealed networks and patterns (Ferster, 2013).

In the literature, the "success" of an information visualization is described through its *measures*. The critical measures of an information visualization vary depending on the context of the information visualization. For example, for an information visualization intended for intensive care doctors, *speed* and *accuracy* are critical measures (Cornish et al., 2019), whereas *reliability* measure is critical in the context of stock markets, and *comprehension* measure might be crucial in the context of public transportation information visualizations. Therefore, to generate a 'good' information visualization, it is necessary to understand the measures within a particular context.

The research on the measures of information visualization has increased in the last two decades, perhaps due to the increasing availability of big data in many disciplines. Hence, there are numerous studies which focus on the definition of individual measures in the literature. On the other hand, there is a lack of consensus on the definitions of those measures, as explained in Chapter 4. One problem is that there are studies that mention different terminology for the same concept. Another problem is that the measures vary in depth and type. There are few studies (Börner et al., 2019; Ajani et al. 2022) that provide a coherent understanding of the measures in relation to each other and to specific contexts.

Nevertheless, information visualizations are still potentially useful tools in areas where complex data needs to be grasped especially by non-scientist audiences. Climate change is one of those areas.

As a global issue, climate change or climate crisis has significant local effects that need public understanding and urgent action (*Climate Action*, n.d.). As the effects of climate change become increasingly visible, the public's knowledge of its urgency and impacts has increased (*Peoples' Climate Vote*, 2021). However, due to the complexity of the issue and vast amounts of scientific data (Ballantyne et al., 2016, p.73) there is a challenge to communicate this issue to the public. Increasingly, studies are being conducted in the climate literature (Wu et al., 2023; Kumpu, 2022; Li et al., 2022; Agin & Karlson, 2021) with the aim of communicating scientific findings to lay people in a manner that will mobilize them to act.

The public's lack of familiarity with scientific terminology and settings (Grainger et al., 2016) intensifies the communication problem. According to Kurnaz (2022), Zengin Demirbilek et al. (2024), and Moser and Pike (2015), there is a lack of mediators who can translate the knowledge and the need for information between the two parties, i.e., scientists and lay audiences. Kurnaz (2022) suggests "an intermediary between the language of the scientists and the language of the general users might help bridge the gap" (p.224).

The gap between scientists and the lay audience is the part where information visualizations come into play; they can be used as mediating instruments. In fact, information visualization's potential as a tool of communication is acknowledged in the literature (Moser, 2010; Moser and Pike, 2015; Ballantyne, 2016; Kumpu, 2022). DeCock-Caspell and Vasseur (2021) argued that information visualizations can be

effective in not only engaging lay audiences but also in mobilizing knowledge. Apart from particular measures and case studies, no frameworks were found that established the measures of information visualizations that can effectively fill the mediation role in the climate crisis. Consequently, this dissertation investigates the measures of information visualizations within the climate change context, proposing a conceptual framework to identify key evaluation criteria for effective climate change visuals.

This study adopts an exploratory, inductive methodology, integrating multiple research methods to comprehensively examine information visualization measures within the climate change context. Initially, exploratory interviews with expert designers provided foundational insights into prevalent measures and their applicability. Subsequent workshops involving academics, design professionals, and NGOs facilitated deeper exploration of these measures, highlighting nuances and interrelations. Finally, an expert survey validated and expanded upon these findings, forming a conceptual framework identifying critical visualization measures such as actionability, enlightening capability, emotional resonance, curiosity evocation, localization, personalization, and positivity in relation to three communication goals.

1.1 Aim of the Study

The aim of the study is to explore the measures of information visualizations and their interrelations within the climate change context. To fulfill this aim, a conceptual framework of information visualization measures is created for the specific context of climate change.

1.2 Research Questions

The following are the research questions of this dissertation:

RQ1: What are the measures of information visualization?

RQ2: Which measures are prominent for climate change context?

RQ3: How do information visualization measures interrelate within climate change context?

1.3 Dissertation Outline

Following the introduction, the dissertation is structured into seven chapters, each focusing on a different dimension of the research conducted:

Chapter 2: Background: Fundamentals of Information Visualization and Climate Change Communication. This chapter provides foundational knowledge necessary to understand the broader context of the research. It begins by introducing fundamental concepts related to information visualization, including definitions and terminology. It discusses the evolution of information visualization as a discipline, highlighting key historical developments and contributions from various fields such as design, cognitive science, data science, and communication. Additionally, this chapter classifies and elaborates on different types of visualizations according to their functions, such as comparison, correlation, distribution, geolocation, part-to-whole, and trends over time. The second part of the chapter addresses climate change communication, emphasizing the complexities and challenges inherent in effectively conveying scientific knowledge about climate change to diverse audiences. The discussion includes audience segmentation, evolution of communication strategies, emotional and motivational dimensions of climate messages, and localized communication approaches. It also examines barriers to effective communication such as scientific uncertainty and complexity, as well as the critical role of information visualization in overcoming these barriers to enhance public engagement.

Chapter 3: Methodology. This chapter details the research methodology employed in this dissertation. It is divided into three major stages: exploratory interviews, workshops, and a survey study. The chapter outlines how each of these research stages was planned, executed, and analyzed. The first stage, exploratory interviews with expert designers, aimed to gain an initial understanding of the measures used in evaluating the effectiveness of information visualizations in the climate context. Interview protocols, participant selection criteria, and analytical approaches are clearly detailed. In the second stage, five workshops were conducted involving diverse participants, including academics, design professionals, and representatives from non-governmental organizations (NGOs). This part explains workshop objectives, participant recruitment strategies, materials utilized, specific procedures followed during the workshops, and analytical process applied to evaluate results. The third and final stage describes a survey conducted with expert designers to validate and expand upon the insights gained from earlier phases, ultimately contributing to the formation of a comprehensive conceptual framework. Detailed descriptions of survey design, participant demographics, data collection, and methods of statistical analysis employed in interpreting survey results are included in this chapter.

Chapter 4: Measures in Information Visualization. In this chapter, an extensive review of existing literature on measures in information visualization is presented. This chapter defines and categorizes various measures critical to evaluating information visualizations, specifically examining their relevance to communicating climate change. Measures are grouped under different orientations: perception and cognition-oriented measures (e.g., comprehension, memorability, clarity, saliency), task-oriented measures (e.g., accuracy, speed), affect-oriented measures (e.g., credibility, engagement, aesthetics,

enjoyment), and goal-oriented measures (e.g., actionability, personalization). The literature review provides detailed definitions, discusses the relevance of each measure within the broader information visualization field, and contextualizes these measures within the climate change communication framework. Additionally, the chapter explores the interdependencies among these measures and their relationship with usability considerations.

Chapter 5: Preliminary Study. In Chapter 5, the findings from the exploratory interviews conducted with expert designers as part of the preliminary study are presented. This chapter summarizes the insights obtained regarding the most significant evaluation criteria and measures identified during these interviews. It explores participants' views on the relative importance and practical application of different measures in the context of climate change visualizations. The chapter also includes detailed discussions on the implications of these findings for subsequent stages of the research, outlining how initial insights shaped workshop activities and informed the design of the survey. Conclusions drawn from the preliminary study provide a crucial foundation for deeper exploration in the subsequent chapters.

Chapter 6: Findings and Results of Workshops and Survey. This chapter discusses the results and findings obtained from five workshops and the survey conducted with expert designers. It first describes detailed findings from each workshop, highlighting participants' perspectives, discussions, and collaborative activities aimed at identifying, prioritizing, and contextualizing key information visualization measures. The chapter systematically discusses identified measures, including actionability, enlightening qualities, emotional engagement, curiosity-evoking aspects, localization, personalization, and positivity, among others. Furthermore, the comparative insights from graphic

designers versus NGO representatives are highlighted to underscore differing perspectives. The second part of this chapter presents a comprehensive analysis of survey findings, including quantitative results from Likert-scale responses and qualitative insights from open-ended survey items. Results are structured around key objectives defined in the methodology, specifically assessing the relationships between identified visualization measures and overarching communication goals, such as building trust, fostering clear and inclusive communication, and motivating action. Additionally, the chapter synthesizes cross-goal insights to propose a coherent conceptual framework for effectively evaluating climate change visualizations.

Chapter 7: Conclusion. In the concluding chapter, the dissertation summarizes key research findings and highlights significant contributions of the study to the fields of information visualization and climate change communication. The chapter reflects on the strengths and potential implications of the developed conceptual framework, emphasizing how it can guide future practices in designing and evaluating effective climate change visualizations. Furthermore, this chapter acknowledges limitations of the current research, such as methodological constraints, participant selection, and potential biases, offering a transparent critique of the research process. Finally, the conclusion identifies promising directions for future research, including potential studies to test and refine the conceptual framework further, suggestions for practical applications in professional design practice, and opportunities for extending the research into related areas or different contexts.

2. BACKGROUND: FUNDAMENTALS OF INFORMATION VISUALIZATION AND CLIMATE CHANGE COMMUNICATION

As an interdisciplinary field, information visualization combines design, cognitive science, data science, and communication to create insightful visual representations out of unstructured data. This section begins by defining key terminology, presenting a brief history of information visualization, and discussing various types of visualizations commonly used today. Following this foundational overview, the focus shifts to climate change communication, examining how visualizations can effectively address communication challenges inherent in engaging diverse audiences on this urgent global issue. By laying out these fundamentals, this section establishes a structured theoretical and practical foundation for understanding how information visualizations function as essential tools for enhancing public awareness, engagement, and informed action on climate change.

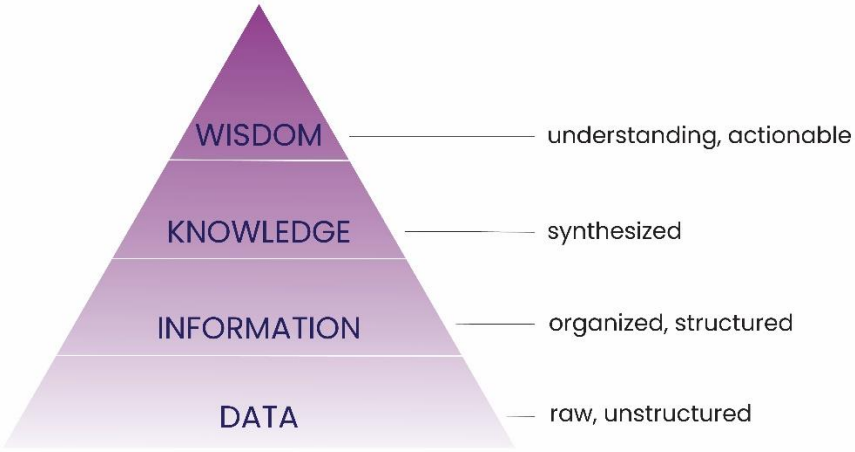
2.1 Defining Information Visualization

Prior to defining what an information visualization is, understanding terms *information* and *data* might be essential, as they form the foundational building blocks of visualization by determining what is being represented. The distinction between information and data is not as obvious as one might think. Data may be thought of as the facts or particulars that are used to derive information. It refers to any measurements or observations that are gathered for the purpose of providing information (*Data | Australian Bureau of Statistics*, 2023). Individual items or singular bits of data are called *datum*. *Datum* translates as "something given," where "something" refers to a part of information (Meirelles, 2013, p. 204). Everything from a numerical fact to a person or a number can

be considered to be the piece of information. It is uncommon for individual bits of data to be valuable on their own. Putting data into context is necessary in order for it to be transformed into information (*Data vs Information - Difference and Comparison | Diffen*, n.d.). There are three main types of data; nominal, ordinal and quantitative. Nominal includes things, objects, items, names and all contexts. Ordinal data is about ranks and orders whereas quantitative data are measurable and numeric (Meirelles, 2013, p. 205). Information, on the other hand, refers to the transformation of data into something usable by processing, organizing, and arranging it in a specific context (*Data vs Information - Difference and Comparison | Diffen*, n.d.; OECD, 2008).

The DIKW Pyramid (Data Information Knowledge Wisdom Pyramid) is a conceptual structure that illustrates the hierarchical link between data, information, knowledge, and wisdom (see Figure 2.1). This exemplifies how raw data may be converted into insights that can be put into action, which can ultimately lead to the making of intelligent decisions. Numerous fields, including data science, information systems, and knowledge management, make extensive use of the DIKW design. It is uncertain who has come up with this pyramid but Milan Zeleny is suggested as the one who has turned the relationship between these terms into a hierarchy in 1987. However, other scholar such as Joseph W. Firestone and Mark W. McElroy, have challenged the pyramid in their 2003 study with the proposal of "knowledge life cycle" where data and knowledge are related to pre-existing information (Wallace, 2007, p.15).

Figure 2.1 *The DIKW Pyramid Inspired from Kirill Soloviev's Depiction*



Taking the DIKW pyramid as a foundation, this dissertation assumes information as the organized and structured data and therefore use the term *information visualization* exclusively since visualization requires a selected, organized and structured set of data. However, visualization designer may collect and clean data before proceeding with the design, they may also start with an already-prepared data provided by others. This study will focus on the design of visualizations and leave out data collection and cleaning processes.

2.1.1 Information Visualization as a Field

Information or data visualization is representing unprocessed information and/or data via graphical elements that are inclusive of spatial factors such as position, size, color and shape to present connections and patterns that can be derived from the data (Ferster, 2013, p.5). This includes infographics, simple statistical graphs, maps, topological representations and various other types of visualization which will be explained in detail below. Meirelles (2013) define infographics as visual presentations that combine visual elements (such as images, symbols, maps, graphs) with verbal language in order to

convey information that would not be attainable in any other way. On the other hand, Sorapure (2019) differentiates infovis (information visualizations) from infographics by pointing out that infovis are interactive whereas infographics are static (p. 2). Purchase et al. (2018) define infographics as quantitative data visualizations often designed with images and embellishments. Information visualizations are more than just creative interesting visuals, they enhance cognitive processes (Card, 2012, p. 539). One thing that should be taken into consideration is that there are several definitions and points of view about what constitutes information visualization. Furthermore, there is no definite consensus on the scope of information visualization or the specific features that it contains.

The field draws from a variety of disciplines, including design, cognitive science, data science, and communication studies, which is reflected in the diversity that exists within it. As a matter of fact, information visualization is an interdisciplinary field, which has its origins in computer science, cartography, statistics, and lately incorporates input from the humanities, art, and design (Shen, 2018). According to Andy Kirk (2012), information visualization necessitates a comprehensive and extensive understanding of a number of fields that have previously been considered separate, such as computer science, graphic design, mapping, and cognitive science. Kirk (2012) also states that because data visualization is such a dynamic and growing field, with this one-of-a-kind combination of art and science defining its practice, it is always going to be impossible to establish a single definition that is ideal, generally agreed upon, and excellent in every manner. As an interdisciplinary and relatively young field of study, information visualization field includes a multitude of definitions and a lack of inclusive theory.

Purchase et al. (2008) point to this problem of information visualization as lacking a well-defined underlying theory and this creates challenges. The lack of theory makes it difficult to assess and justify the tools that are built, and it also means that the value of a new visualization approach cannot be identified in advance of its application. Purchase et al. (2008) do not claim that a single theory would be able to include the entirety of the area of information visualization; rather, they state that it is possible that the field requires numerous theories that operate on a variety of levels.

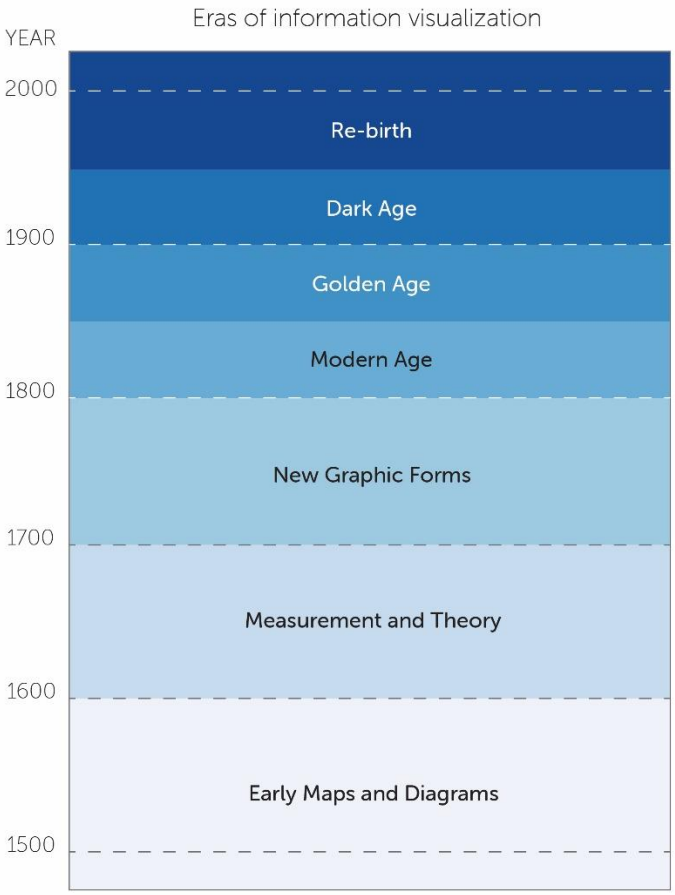
In an emerging field of study, where there is a lack of solid theories, approaching the problems from various stands points become significant. From an exploratory, inductive point of view, the study of measures in information visualization may enable researchers to discover effective information visualizations and their designs according to contexts, audiences and different applications. The inductive approach enables researchers to recognize patterns and gain insights directly from observations, interviews, case studies, user studies or other methods. With these methods it is also possible to be flexible and sensitive to the diverse nature of information visualization. Also, it is possible to keep research relevant and adaptable even as new technologies, data formats, and audience expectations develop. A brief look at previous examples of information visualizations may inspire a point of departure for exploratory studies.

2.1.2 Brief History of Information Visualization

Recording and keeping data dates back to prehistorical times. As the earliest map ever found is in *Çatalhöyük* (Konya, Turkey) dating back to circa 6000 BCE, other very old examples include the clay tablets recording amounts of barley produced by Sumerians (circa 3300 BCE) and *quipus* which are knots tied around ropes to keep quantities used by Incas (circa 1000 CE) (Friendly & Wainer, 2021, p. 6-12). However, the bar charts

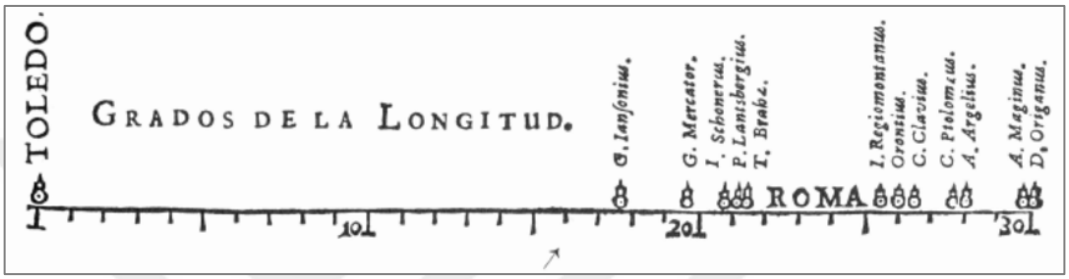
and line graphs that we commonly see are concentrated around the last 400 years in history. Friendly and Wainer (2021) has created a timeline that shows milestones in history of information visualizations (see Figure 2.2). A quick view of this timeline shows that around 1700s new graphic forms emerge and information visualizations develop over time until the first quarter of 1900s. The silence in developments of the field will be broken again in mid-century and with the wide-spread use of computers it is re-born again.

Figure 2.2 *Timeline Showing Eras of Information Visualization, Based on Friendly and Wainer's Timeline (2021, p. 4)*



In search of the first graph ever made, a graph created by Van Langren in 1644 that represented twelve different determinations of the longitude distance between Toledo and Rome comes up (see Figure 2.3).

Figure 2.3 *Van Langren's 1644 Graph Showing Measured Distances from Toledo to Rome*



Source: Tufte (1997, p.15) image in public domain.

Plotting of data was the method to create graphs before the 1700s (Friendly & Wainer, 2021, p. 20). Towards the end of the 1700s and the first quarter of 1800s, through William Playfair's graphical innovations, which include the line chart, bar chart, and pie chart, the audiences met the graphical forms that are utilized the most frequently in the modern world today (p. 24). Following that the latter half of the 1800s is considered to be the "Golden Age of Graphics." This period was characterized by an "avalanche of numbers", which was a flood of information on many societal concerns such as business, medical issues, and criminal activity (p. 27). In order to properly describe and analyze data, statistical theory was developed. Meanwhile, advancements in printing technology made it possible to distribute graphics that were multicolored and stylistically created. A unified visual language and approach to visual thinking were the defining characteristics of this era, which brought along a worldwide excitement for data graphics. Some of the most well-known examples of information visualizations from this time include John Snow's "Cholera Map" 1854 (Tufte, 2001, p.27-31), Florence Nightingale's "Rose

Diagram" 1859 (Florence Nightingale's, 2020), Charles Joseph Minard's "Map of Napoleon's March" 1869 (Tufte, 2001, p.40-41). In 1880, Luigi Perozzo took the two-dimensional graphs and applied a three-dimensional method to show life expectancy. His graph was one the very first and famous 3D graphs (Friendly & Wainer, 2021, p. 194-195). Later Perozzo also made a 3D tangible data model, probably one of the first data sculptures (p. 197).

There were several important information visualizations worth noting from the beginning of the 1900s. Over sixty statistical hand-crafted charts, graphs, and maps were included in the display that W. E. B. Du Bois created and presented at the Paris Exposition in the year 1900. The booth depicted the history of African Americans in the United States (*Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization*, n.d.). A second significant example from the first quarter of 1900s was the Isotype. Isotype (International System of Typographic Picture Education) was developed by a team of designers, statisticians and others led by Otto Neurath in the 1920s. Their fundamental aim was to create a pictorial system that enabled communicating statistical data with broad audiences (Schreder et al., 2018). The name Isotype comes from Greek iso (meaning same) and typos (meaning type or form), this relates to one of Isotype's characteristics, using the same consistent form for each concept (Mayr and Schreder, 2014). There were three rules that were followed for creating icons as Isotype: The icons had to be used consistently for the same concept, each icon had to be the same size and the icons designed had to have some sort of resemblance to the subject they represented. The icons within an Isotype are always countable and each icon represents a certain number. The icons should be designed as simple as possible and any detail given should have a function (Schreder et al., 2018). More than 2,000 symbols and icons were created

as Isotypes (Mayr and Schreder, 2014, p. 139). The last example that needs noting is Harry Beck's "London Underground Map" 1933 (Matters, n.d.). As an electrical engineer, Beck has revolutionized the complicated metro maps into simple to follow and understand stylistic maps.

After the 1930s, innovations slowed down. The period from the mid-1930s to the mid-1960s has been called a "modern dark age" for statistical graphics because of a general decline in interest in the subject during that period. This decline coincided with increases in quantification and statistical modeling occurring at the same time. Techniques during this period, such as factor analysis and principal components analysis shifted their emphases away from that of display for graphical output. The pioneering work of Tukey in the United States and Bertin in France throughout the 1960s and 1970s led to a re-awakening of interest in visualization techniques (Friendly & Denis, 2001). With the development and wide-spread of computers, new types of visualizations emerged.

Today, there are so many applications and software that aid in creating information visualizations. These include Tableau, Microsoft Power BI, Google Charts, and you can still create simple charts in Microsoft Excel, IOS Numbers or it is possible to directly code charts and graphs on R Studio or using Python. There are also plugins created to use with Adobe Illustrator for making charts such as Datylon and even Canva (a graphic design platform designed for lay people to use) has graph making tools incorporated within. Adding to that, animated and web-based interactive visualizations are common to see nowadays. However, this study focuses on static information visualization that are shared online. It is also important to note that two web-based

catalogues datavizproject.com and datavizcatalogue.com are online sources that present 165 different types of charts, graphs and diagrams that are used today.

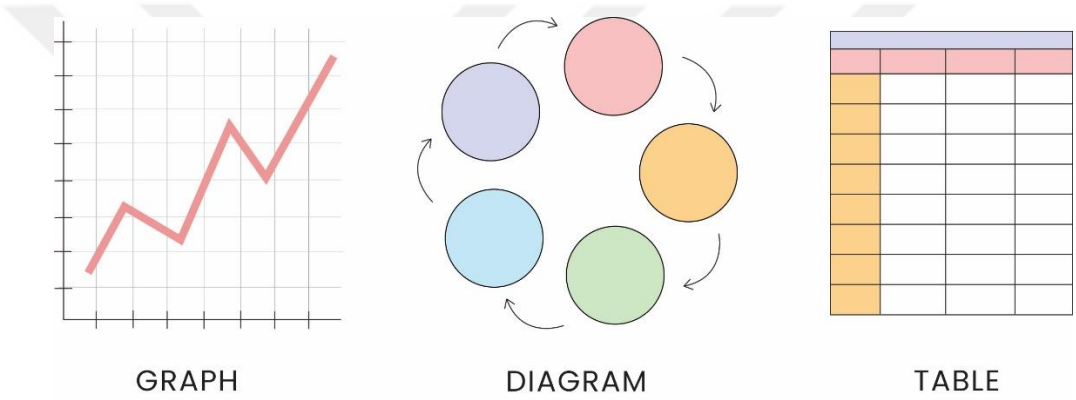
2.1.3 Types of Information Visualizations

Before delving into different types of charts, it is essential to define basic terms such as *chart*, *graph*, *diagram* and *table* (See Appendix F for a glossary of terms used in information visualization discipline). Many researchers use *chart* and *graph* interchangeably. Sometimes the term is selected by researchers in accordance with an academic convention. Alternatively, they are sometimes utilized by individuals in order to differentiate between various sorts of representations (*A Guide to Charts*, n.d.). According to the definition in Oxford's *World Encyclopedia* a *graph* is a "[d]iagram representing a relationship between numbers or quantities. Many graphs use the Cartesian co-ordinate system. Other forms include bar charts, where a series of figures is represented by lines of various lengths, and pie charts, in which quantities are represented by sectors of a circle" (*Graph*, n.d.). In addition, the *Oxford Dictionary of English* (3rd ed.) defines a *chart* as "a sheet of information in the form of a table, graph, or diagram: *the doctor recorded her blood pressure on a chart*" (*Chart*, n.d.). From these definitions, it can be concluded that a *chart* and a *graph* have a similar meaning, but the *chart* seems a broader term including all sorts of graphs, diagrams and tables.

A *diagram*, on the other hand, is "a simplified drawing showing the appearance, structure, or workings of something; a schematic representation: *a diagram of the living room"* (*Diagram,* n.d.). And a *table* is "a set of facts or figures systematically displayed, especially in columns: *the population has grown, as shown in table 1" (Table, n.d.)*. Therefore, diagrams do not make use of the Cartesian co-ordinate system, and a table has a very specific layout with columns and rows (see Figure 2.4).

There are several ways to group information visualizations. One way is to group visualizations by type; chart, diagram, geospatial, plot and table. The second way is to group visualizations is by function. The functions are comparison, correlation, distribution, geolocation, part-to-whole and trend over time. Sorting by function makes it easier to identify the purpose of a visualization and select the most appropriate format for conveying specific information.

Figure 2.4 *Graph, Diagram and Table*



For example, if the goal is to show how values change over time, a trend visualization such as a line graph would be suitable. On the other hand, if the aim is to highlight relationships or patterns between variables, a scatter plot or correlation graph might be more effective.

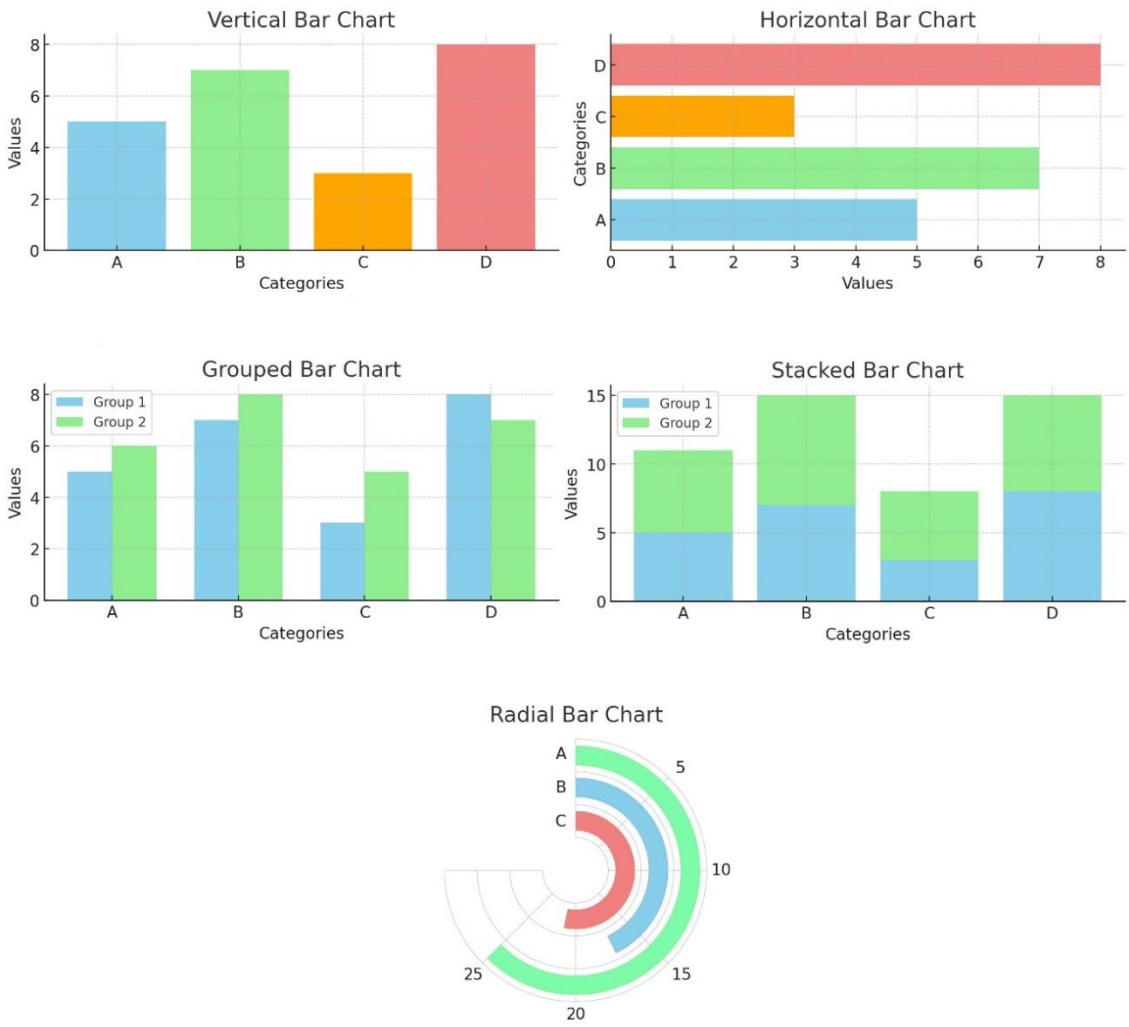
2.1.3.1 Charts for Comparison

Comparisons through charts are very helpful in demonstrating similarities, differences, trends, and patterns that exist across various datasets. The audience is provided with insightful information, which assists them in making judgments based on accurate data (Chowdhury, 2023). Charts under the comparison function include bar charts (vertical, horizontal, radial, stacked, grouped), lollipop chart, bullet chart, dot plot,

dumbbell, pictogram, icon chart, range chart, parallel coordinates, radar chart, nightingale chart, waterfall chart, matrix chart, small multiples, word cloud, slope chart, alluvial diagram, table chart, categorical scatter plot, Chernoff faces and quadrant chart. Among this very long list of charts, bar charts are the most used and most familiar chart type (see Figure 2.5).

Bar charts are made up of a collection of rectangles that have lengths that are proportionate to the values that they represent. Each rectangle, which is represented by the bar, is a component of a single category (*Understanding and Using Bar Charts | Tableau*, n.d.). Comparisons may be made quite easily using bar charts. For example, changes in size and color are more difficult to make out than differences in bar length, which are easy to see (Hess, n.d.). Because of their ease of use, bar charts are among the most often used charts.

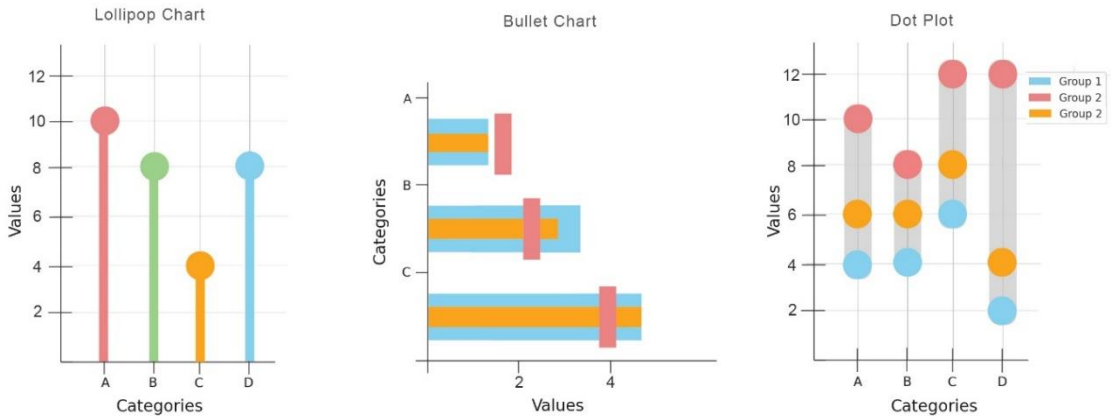
Figure 2.5 *Types of Bar Charts*



A lollipop chart illustrates the connection that exists between a category variable and a numerical variable. This particular style of chart is made up of a line that illustrates the magnitude, and it concludes with a dot or a circle that emphasizes the data value (Hess, n.d.). There is a form of chart known as a bullet chart that is intended to serve as a benchmark against a goal value and ranges. The primary purpose of this chart is to present performance statistics. It is a highly space-efficient chart. In terms of appearance, bullet charts are comparable to graphs that combine bar and column charts with progress bars. One bar or column is used to display the findings of the analysis (*Understanding and*

Using Bullet Graphs | Tableau, n.d.). By charting one or more dots per category on a numerical axis, a dot plot is able to display one or more quantitative values for each category. It is relatively simple to create a comparison between the categories when using a dot plot that simply has one value for each category. When there are many values for each category in the dot plot, it is also possible to compare the values within the categories themselves. Connecting the dots turns this chart into dumbbell chart. Again, this chart type is very space-efficient (Hess, n.d.) (see Figure 2.6).

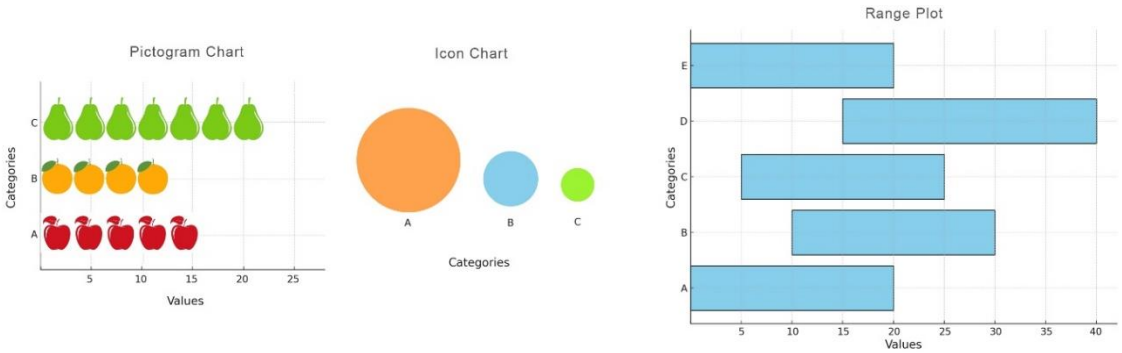
Figure 2.6 *Lollipop Chart, Bullet Chart and Dot Plot*



The pictogram chart is an information visualization that represents data via the use of icons, symbols, or even tiny images such as pictures. Every single one of these symbols is associated with a certain category. There are some similarities between pictogram charts and bar charts; however, rather than utilizing bars, pictogram charts display symbols (Hess, n.d.). These are related to Isotypes that were discussed in the previous section. An icon chart, which is also called a proportional area chart, is a chart type to use when the placement of the markers is not dictated by data. Values may be associated with the color and dimensions of the icons. The icon chart use area instead of length to represent values, enabling it to convey a broader spectrum of values in a concise

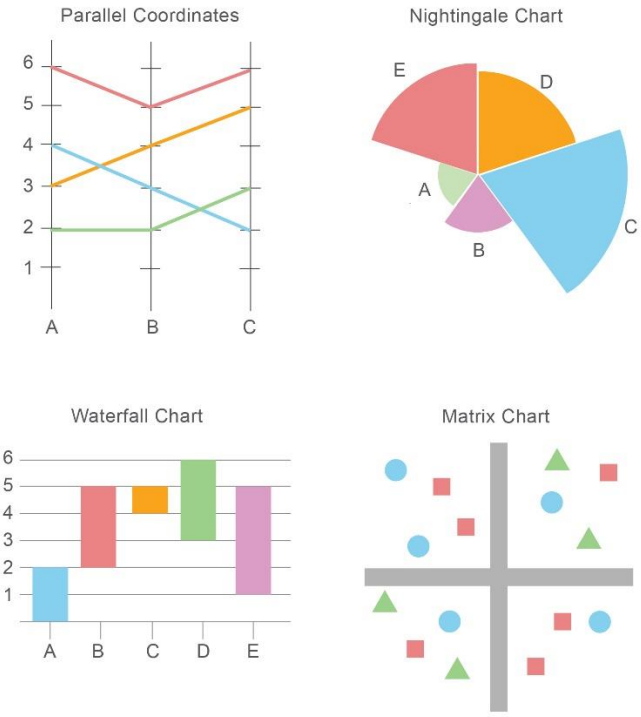
manner. Similar to a bar chart, a range plot displays two values for a category rather than a single number. It is also called column range or floating bar chart. A range plot displays two points interconnected by a line. This line denotes the disparity, or interval, between these points and implies a direction of change (*Column Range*, n.d.) (see Figure 2.7).

Figure 2.7 *Pictogram Chart, Icon Chart and Range Plot*



The parallel coordinates chart is similar to a line chart; however, it plots categories on the horizontal axis instead of temporal values. It enables the representation of several categories or dimensions. Nightingale chart (or the Rose Diagram) is very similar to a pie chart visually; but a Nightingale chart does not convey a part-to-whole connection. It contrasts values among categories in a manner similar to a bar chart, but in a radial format. A waterfall chart is a graphical representation that typically illustrates positive and negative value changes between two points, facilitating the comprehension of the cumulative impact of these changes (i.e., the net change). This chart examines not only the initial and final values of the data but also illustrates each unique positive or negative change that occurred. To visualize the relationship between two or more variables in a data collection, a matrix chart is a form of chart that is frequently used as it displays many values within a grid structure (Hess, n.d.) (see Figure 2.8).

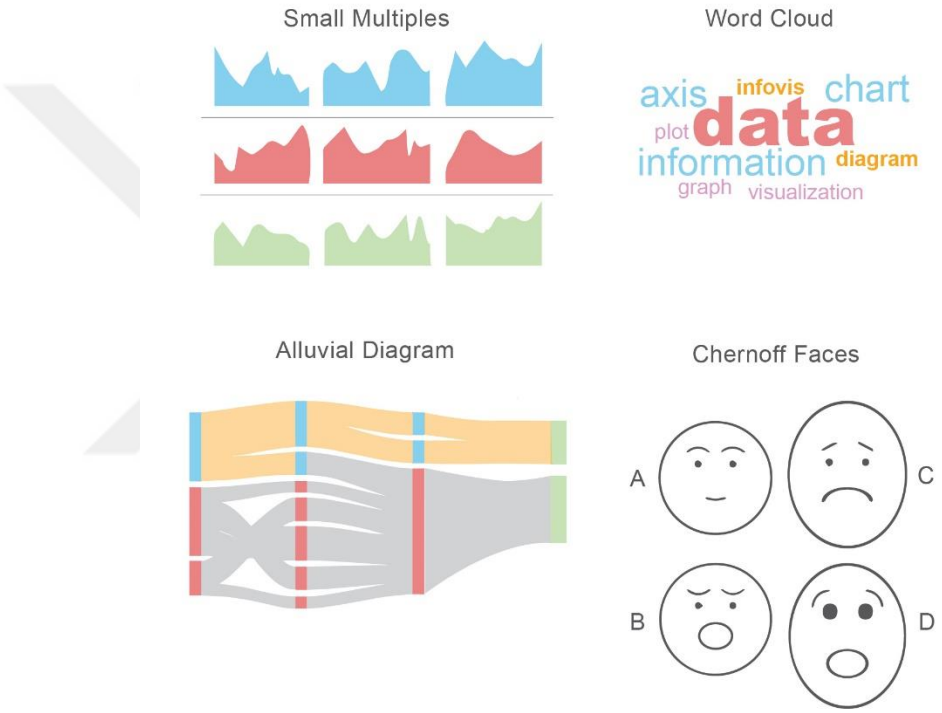
Figure 2.8 *Parallel Coordinates, Nightingale Chart, Waterfall Chart and Matrix Chart*



Small multiples is a technique for showing multiple charts of the parts of a data set. It enables the viewers to compare parts of data via multiple visualizations (Yau, 2011). A word cloud is also not a traditional visualization but a visual cluster of various words that have different sizes proportional to the frequency with which they appear within the data collection. If a keyword appears repeatedly that word is shown larger and sometimes bolder. Another diagram that is used for comparisons is the alluvial diagram. It was initially intended to illustrate how the structure of a network may change over time. Alluvial diagrams are called after alluvial fans, which are naturally generated by the soil that is deposited by flowing water. This is a reference to both the visual look of the diagrams as well as the particular emphasis that they place on flow (*Alluvial Diagram*, n.d.). A final and rarely used chart is the Chernoff faces. In 1973, Herman Chernoff suggested that facial forms may be used to represent a number of variables in a data

collection. This would enable the user "to visually cluster the data by mapping numbers to the size and curvature of the face, the location of the eyes, the length of the nose, the position of the mouth, and other similar characteristics" (*Chernoff Faces*, n.d.) (see Figure 2.9).

Figure 2.9 *Small Multiples, Word Cloud, Alluvial Diagram, Chernoff Faces*



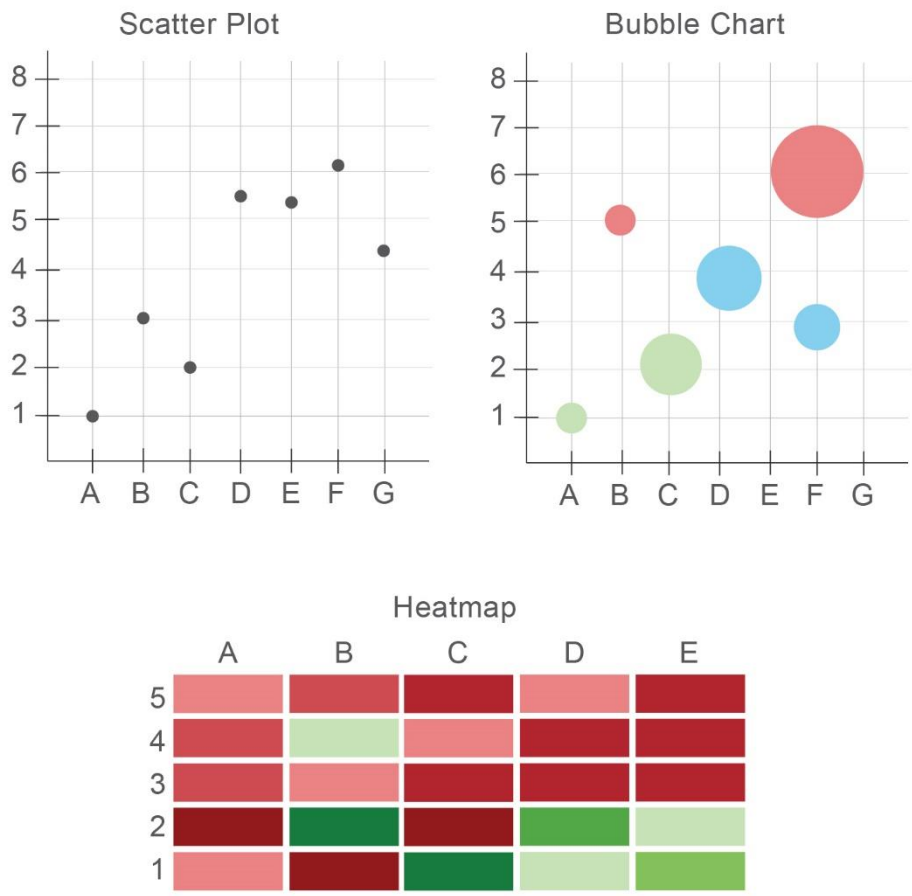
2.1.3.2 Charts for Correlation

The term *correlation* refers to the tendency for one item to change in a particular manner when another thing changes (Yau, 2011). A positive relationship exists when both variables increase together, a negative relationship exists when one variable increase while the other variable drops, or a relationship does not exist at all. A number between 1 and -1 is used to convey correlation, where 1 represents a perfect positive correlation, -1 represents a perfect negative correlation, and 0 indicates that there is no relation at all.

A frequent method for visualizing it is through the use of scatter plots, in which the arrangement of dots displays the strength of the relationship as well as the direction it is moving in. The identification of trends and patterns is facilitated by correlation, but it does not demonstrate causality (Numeracy, Maths and Statistics - Academic Skills Kit, n.d.). Scatter plot, bubble chart and heatmap are the tree common charts that are used for visualizing correlation.

By showing the values of two numerical variables as dots between the horizontal and vertical axes, a scatter plot is able to display the values of those variables. The location of each observation in a two-variable plane may be easily understood through the use of straightforward data markings of a single size. It is common practice to employ a scatter plot in order to demonstrate relationships between numerical variables and to recognize patterns (Hess, n.d.) A scatter plot also works for showing distributions. A version of the scatter plot, bubble charts are a type of chart in which the data points are substituted with bubbles rather than the traditional dots. Adding to the position of variables on the Cartesian coordinates, the size of the bubble changes according to a third variable (Yau, 2011). Heatmap is the third common chart type that shows correlation. To display the high-to-low quantitative values of the information that has been gathered, a heatmap makes use of a color palette that ranges from hot to cold (Jurkonytė, 2021). The progression of the data over time may be shown by including a date or a time scale on the x-axis of the chart. The layout of the heatmap is a table (Hess, n.d.) (see Figure 2.10).

Figure 2.10 *Scatter Plot, Bubble Chart and Heatmap*



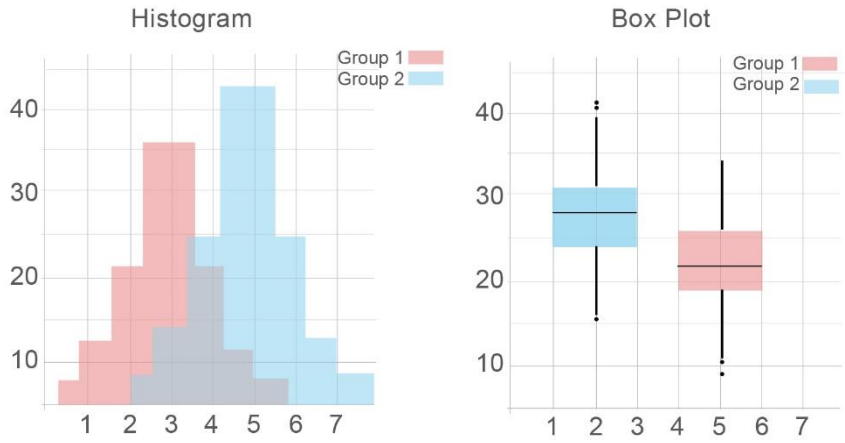
2.1.3.3 Charts for Distribution

A list of things or numbers may be summarized statistically in the most fundamental way possible by referring to its distribution. A distribution may be thought of as a condensed description of a list that has a great number of elements (Irizarry, 2020). The process of assessing how data is distributed, its central tendency, and the variability that exists across several groups or situations is referred to as distribution. Through the examination of metrics such as the mean, median, and mode (central tendency), range, interquartile range, and standard deviation (spread), as well as characteristics such as

symmetry, skewness, and kurtosis (shape), it is possible to discover patterns, trends, and outliers that are not readily apparent in raw data (*What Are Good Data Visualization Techniques to Compare Distributions in R?*, 2024). The most common types of charts used for distribution function are histograms, box plots, density plots and violin plots.

Histograms are a form of chart that have a visual appearance that is similar to column charts. In a histogram, there is no empty space between each rectangle, which is the primary visual distinction between a column chart and a histogram. In a histogram, the numbers are organized into ranges, which is not the case in column charts. The frequency of a variable is shown through the length of the columns (Hess, n.d.). An overview of the distribution of a dataset may be obtained through the use of box plots, which are sometimes referred to as box-and-whisker plots. In addition to the median and quartiles, they display any probable outliers (see Figure 2.11).

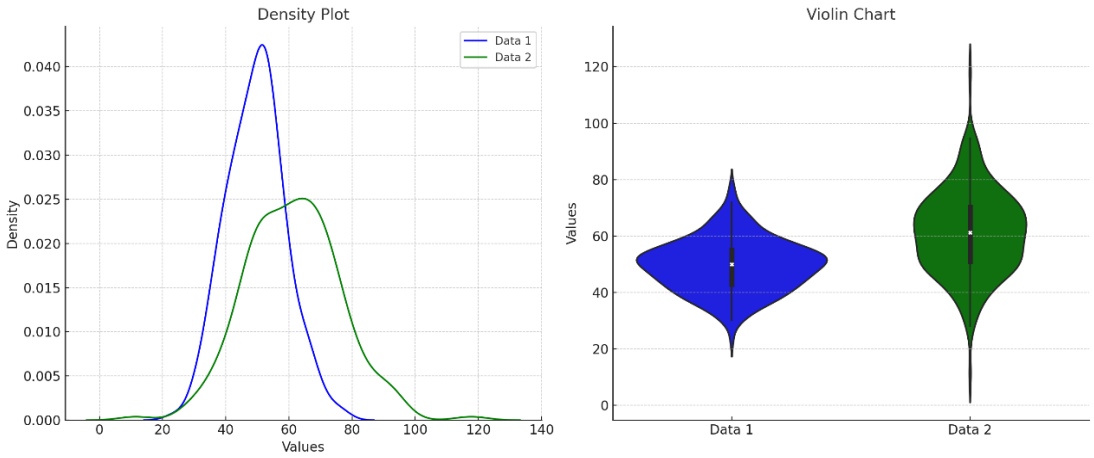
Figure 2.11 *Histogram and Box Plot*



The distribution of a numerical quantity can be represented graphically through the use of a density plot. It does this by utilizing a kernel density estimate in order to display the probability density function of the variable. Although it is a smoother version

of the histogram, it is utilized in the same way as the histogram. Studying the distribution of one or a few variables may be accomplished through the use of density plots (Irizarry, 2020). A violin plot, similarly, helps visualizing the distribution of a numeric variable for one or more groups. A group or a variable is represented by each individual "violin." The shape is a representation of the density estimate of the variable; the bigger the violin is for a particular range, the more data points there are in that range. Not only does it seem very much like a boxplot, but it also enables a more in-depth comprehension of the distribution (*Violin Plot*, n.d.) (see Figure 2.12).

Figure 2.12 *Density Plot and Violin Plot*



2.1.3.4 Charts for Geolocation

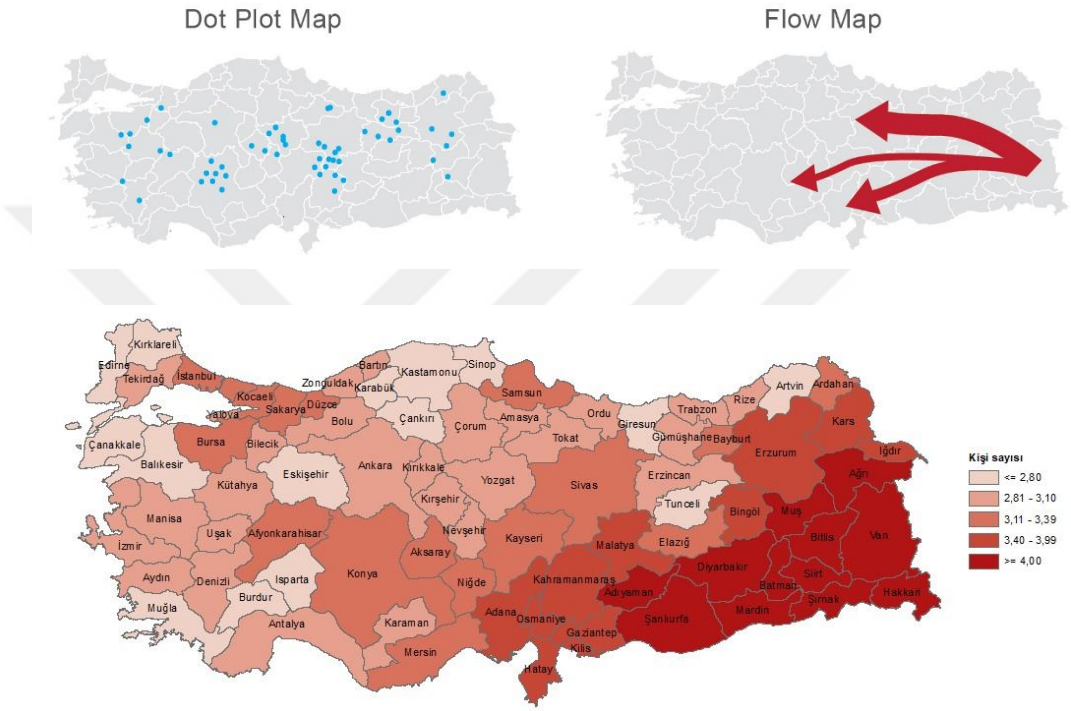
The analysis of geospatial data, on the other hand, involves the presentation and evaluation of abstract information, which is often numerical in nature, within the context of its geographical setting. Cartographic maps serve as geographic reference frames here. It is possible to get insight by observing the relationships between quantities and patterns as they become apparent in the geographical locations in which they are existing (Seipel, 2014, p.229). In simple terms, geolocation visualizations are maps enriched with layers

of data. The most common types of geolocation visualization include dot plot maps, flow maps and choropleth maps.

A dot density map is a kind of map that makes use of a dot or similar symbol to indicate the presence of a certain feature or phenomena. Locations that have a large number of dots on a dot density map suggest that there are high concentrations of values for the selected field, whereas places that have a smaller number of dots indicate that there are lower concentrations. It is possible for each dot on a dot density map to either represent a single recording of a phenomena (or a one-to-one representation) or a specific quantity of the phenomenon (or a one-to-many representation) (*Data Viz Project*, n.d.). John Snow's "Cholera Map" of 1854 is a well-known example from information visualization history. Snow had marked each case of cholera on a map of the neighborhood and was able to identify a cluster of cases near a specific water pump, pointing to the source of the outbreak. Flow maps are a combination of maps and Sankey diagrams that illustrate the movement of quantities from one point to another. These numbers include the number of people traveling, the quantity of commodities being exchanged, or the number of packets in a network. The amount can be determined by the width of the arms of the flow. Flow maps can sometimes be displayed with arrows to indicate the direction in which the movement is occurring. One of the most well-known examples of a flow map is Minard's map, which depicts the catastrophic Russian war that Napoleon initiated in 1812 (*Data Viz Project*, n.d.). And finally, a choropleth map is a type of thematic map in which geographical regions are shaded or patterned in a manner that is proportional to the measurement of the statistical variable that is being represented on the map. For example, population density or per-capita income are examples of such variables. In addition to displaying the degree of variation that exists within a region, the

choropleth map is a convenient tool for seeing how a measurement varies over a geographical area (see Figure 2.13).

Figure 2.13 *Dot Density Map, Flow Map and Choropleth Map Showing Number of People Per House by Turkish Institute of Statistics (2021)*



There are also other visualizations that combine maps with different types of charts. For example, during the Covid pandemic of 2019, it was common to see number of cases represented as bubble charts over the map of the world. Johns Hopkins' red on black dashboard was an example of such bubble maps (see Figure 2.14).

Figure 2.14 *Johns Hopkins Dashboard Showing Global Covid-19 Statistics*



Source: Johns Hopkins University Center for Systems Science and Engineering. (2020). COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE). Retrieved from https://coronavirus.jhu.edu/map.html Image is under Creative Commons Attribution 4.0 (CC BY 4.0)—permitting reuse in scholarly work.

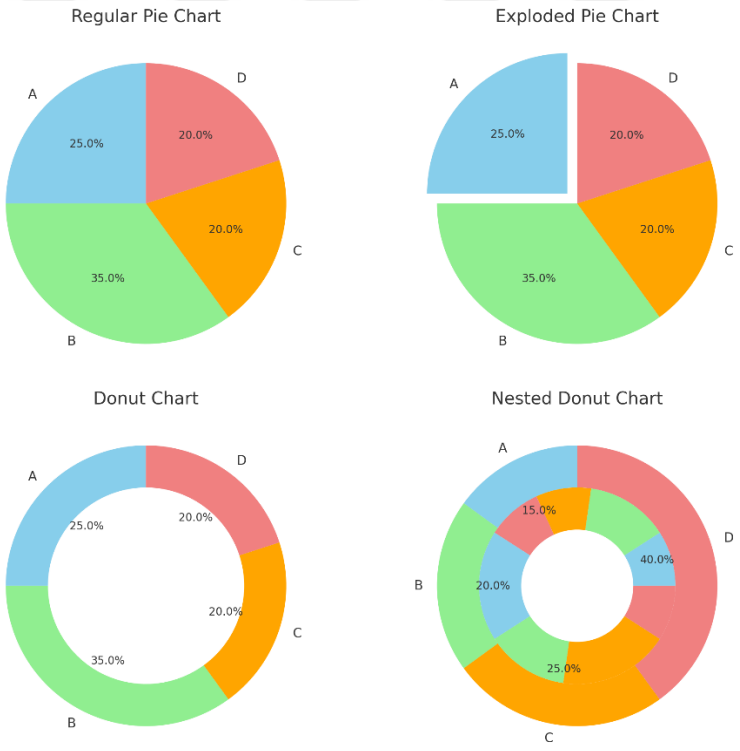
2.1.3.5 Charts for Part-to-Whole

The simplest and most basic version of proportions is part-to-whole. The collection of proportions that add up to one or a collection of percentages that sum up to one hundred percent are represented though visualizations. While it is important to demonstrate how one component is related to the others, it is also important to preserve the impression that the entire data is being presented (Yau, 2011). Pie charts, donut charts, treemaps and sunburst charts are the most common types of charts that serve this function.

A pie chart is a circular graph that illustrates a part-to-whole relationship. It is the most popular style of chart along with bar charts. The data is divided into parts (slices) and the whole set equals to a total (pie). The total of the slices needs to be logically consistent. It is recommended that the sum be rounded up to one hundred if the data is presented in percentages. In the event that the information is presented in absolute amounts, such as dollars, the categories ought to come together to make a meaningful

total. When there are only a few categories, a pie chart is most effective; otherwise, the chart becomes a cluttered mess that is difficult to read (Hess, n.d.). A donut chart is the same as a pie chart except the hole in the middle. The data-ink ratio[1] of a donut chart is better than a pie chart. Since the data is shown by the length of the sectors, rather than the area, it simpler to understand. Because the space in the middle of a donut chart may be utilized to add a title or a noteworthy number that is generated from the data, this is still another advantage of using this type of chart (Hess, n.d.) (see Figure 2.15).

Figure 2.15 *Different Types of Pie and Donut Charts*

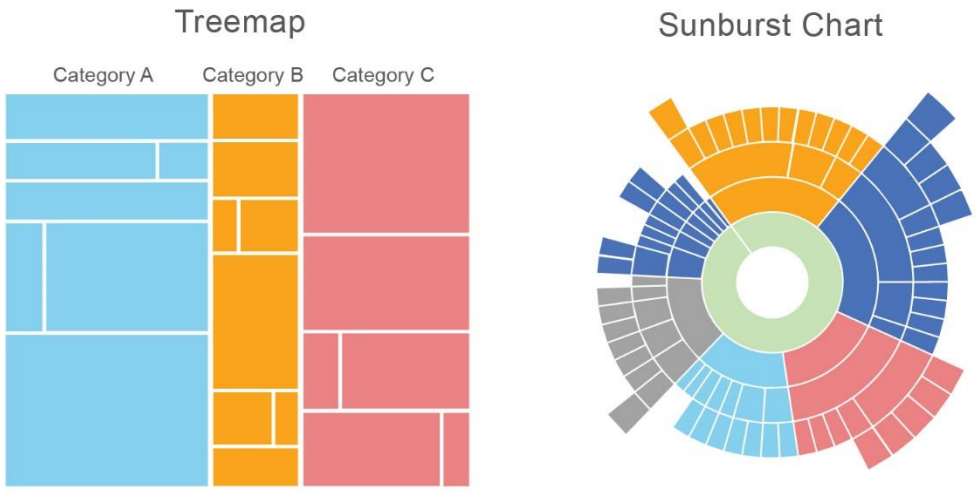


[1] The data-ink ratio is a concept created by Edward Tufte. When compared to the total amount of ink (or pixels) that is utilized in the display as a whole, the data-ink ratio is the proportion of ink that is used to provide real data to the user. Ink used for non-essential or decorative elements is considered wasteful and detracts from the effectiveness of the visualization. There is a big debate about this issue in literature.

As a visual representation, the treemap is made up of rectangles that are layered within one other. Each of these rectangles represents a particular category that falls under a particular dimension, and they are arranged in a hierarchy, sometimes known as a "tree." It is possible to compare and depict patterns and quantities inside a chart that has a restricted amount of space. Relationships between parts and wholes are shown by treemaps. This particular representation was designed by Ben Shneiderman, a professor of computer science at the University of Maryland, with the intention of making the most of a limited amount of living space. "Tree structured node-link diagrams grew too large to be useful," he stated. "As a result, I explored ways to show a tree in a space-constrained layout with the intention of overcoming this limitation" (*Understanding and Using Tree Maps | Tableau*, n.d.).

A sunburst chart is a visualization that shows a hierarchical dataset by means of a series of rings that are concentric and outwardly oriented. There are several distinct levels of hierarchy that correlate to each of these rings. The inner circle is shaped like a donut chart; however each outer ring can be cut into pieces according to the relationship it has with the inner circle, which corresponds to the parent circle. Compared to a treemap, the radial pattern of this chart requires more space than the rectangular form of a treemap, therefore it is less space-efficient (Hess, n.d.) (see Figure 2.16).

Figure 2.16 *Treemap and Sunburst Chart*



2.1.3.6 Charts for Trend Over Time

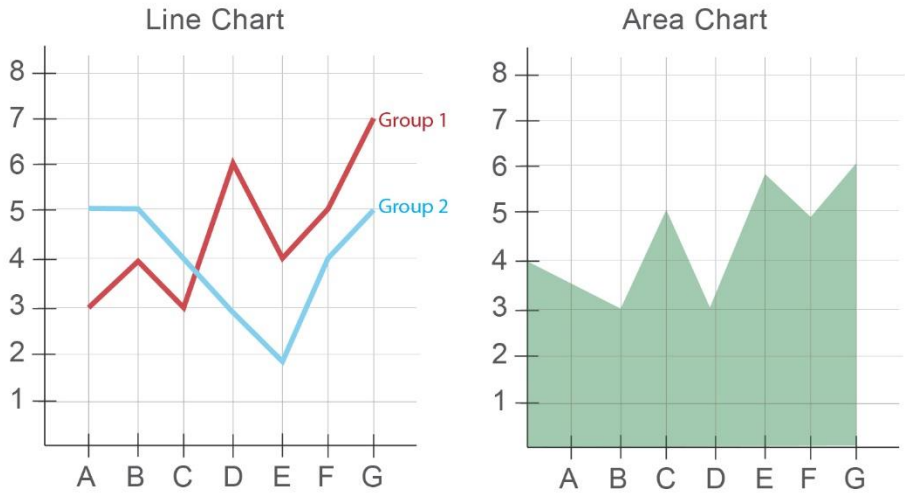
A succession of data points that serves to measure a certain variable over a predetermined amount of time is referred to as time series data. Trend is an example of one of these components. Over an extended period of time, a trend is a pattern in data that demonstrates the progression of a series to values that are substantially greater or lower than they were previously. In other words, a trend is detected in a time series when there is a slope that is either growing or decreasing for the time series. In general, a trend will exist for a period of time and disappear over time (*What Is a Trend in Time Series?*, 2024). To understand trend, one must examine the aggregate data rather than isolated data points to have a comprehensive understanding (Yau, 2011). Line chart and area chart are the two most used charts for this function.

In spite of the fact that they are one of the oldest forms of charts, line charts continue to be among the most often used. They are simple, easy to learn, and adaptable in their use. They are able to display a massive amount of data all at once. One of the most advantageous aspects of line charts is that they can be readily integrated with other

types of charts, such as bar charts or area charts, and can also be used to other types of charts. In a line chart, the data points each represent two different variables, and they are connected to one another by a line in order to illustrate how the data is changing over time. A continuous variable, which is often time, is shown along the x-axis, also known as the independent axis, while the y-axis, also known as the dependent axis, includes a numerical value for a metric of interest (Hess, n.d.). Unlocking powerful narratives about the relative or (perhaps) connected transition of categorical data may be accomplished with the use of line charts (Kirk, 2012).

In many ways, an area chart is similar to a line chart (see Figure 2.17). The values of the data are shown in a manner that is comparable, and lines are used to link them. The distinction lies in the fact that the region that lies between these lines and the x-axis is filled with a color. This aids in visualizing the change in volume over the course of time. Area chart is more concerned with demonstrating a general shift that takes place over a period of time as opposed to focusing on particular data values (Hess, n.d.).

Figure 2.17 *Line Chart and Area Chart*



Area charts, line charts, bar charts, and pie charts are all examples of charts that are commonly attributed to William Playfair as the inventor. With the publication of his book *The Commercial and Political Atlas* in 1786, he included a number of time-series graphs. These graphs included the Interest of the National Debt from the Revolution and the Chart of all the Imports and Exports to and from England from the Year 1700 to 1782. These graphs are frequently referred to as the first area charts in the history of the world (Tufte, 2001).

The background section explored the foundations and evolution of information visualization throughout history and categorized the commonly used visualization types. The historical context and analysis of different chart types and functions demonstrate the diversity and how wide-spread the visualization methods are across disciplines and applications. However, the field remains fragmented, with no unified theoretical foundation, making it essential to study measures that define effective visualizations. By focusing on these measures, researchers and practitioners can develop visualizations that are not only visually appealing but also meaningful and impactful for their intended audiences.

2.2 Climate Change Communication

Climate change communication is a multidisciplinary and evolving field that includes all forms of communication about climate change. It spans across media and formats, aiming not only to inform but also to engage and empower the public in the face of one of the most pressing global challenges. According to Agin and Karlsson (2021), climate change communication serves as an umbrella term that includes all communication activities surrounding climate change (p. 431). Wu et al. (2022) offer a more specific definition, describing it as a total of all communication efforts that help the

public understand and engage with climate change information and scientific knowledge, aiming to address climate challenges by influencing societal attitudes and encouraging behavior change (p. 2). In this sense, climate change communication is not limited to informing people about the facts, but it is also a goal-oriented process of promoting awareness and motivating action.

Early models of climate communication followed a linear transmission model, where a message was sent from a source to a passive audience. However, this approach has since been challenged as overly simplistic (What is Climate Change Communication?, n.d.). As Moser and Pike (2015) explain, climate communication occurs within a complex ecosystem of actors, values, political contexts, and cultural assumptions. Today, scholars emphasize a more interactive, participatory model, acknowledging that messages are interpreted through social lenses, existing beliefs, and emotional frames (Glaas et al., 2017).

As stated by Yale Program on Climate Change Communication, communication about climate change occurs within a rich and complex ecosystem of individuals, institutions, and ideologies. Understanding and action on climate change emerge not from isolated messages, but from continuous and collective communication processes. In many cases, numerous communicators convey a range of—sometimes conflicting—messages through complex communication channels. These messages reach diverse audiences who have their own beliefs, values, and attitudes that affect the interpretation process. The audiences actively construct meaning based on their perspectives and then share it within their own social networks. As a result, communication takes place within a dynamic system composed of individuals, organizations, and institutions that often differ significantly in knowledge, political views, and cultural backgrounds. As a scholarly

discipline, climate change communication aims to explore these processes, build theoretical foundations, and identify more effective ways to communicate and promote meaningful action on climate change (What is Climate Change Communication?, n.d.).

In this context, a relevant communication model is the two-way symmetric communication model. This model is derived from public relations theory. As described by Özel (2015), this model prioritizes mutual understanding, negotiation, and conflict resolution. It encourages active dialogue between communicators and stakeholders, allowing feedback to shape the flow of information and fostering more responsive and inclusive communication strategies (p. 87). Applied to climate communication, this approach supports participatory engagement. And it also enhances the capacity of individuals and organizations to respond effectively to climate-related concerns (Rençber & Arklan, 2023, p. 12). However, to work effectively with communication models, one must understand the qualities of their target audience.

2.2.1 Climate Change Audience Segmentation

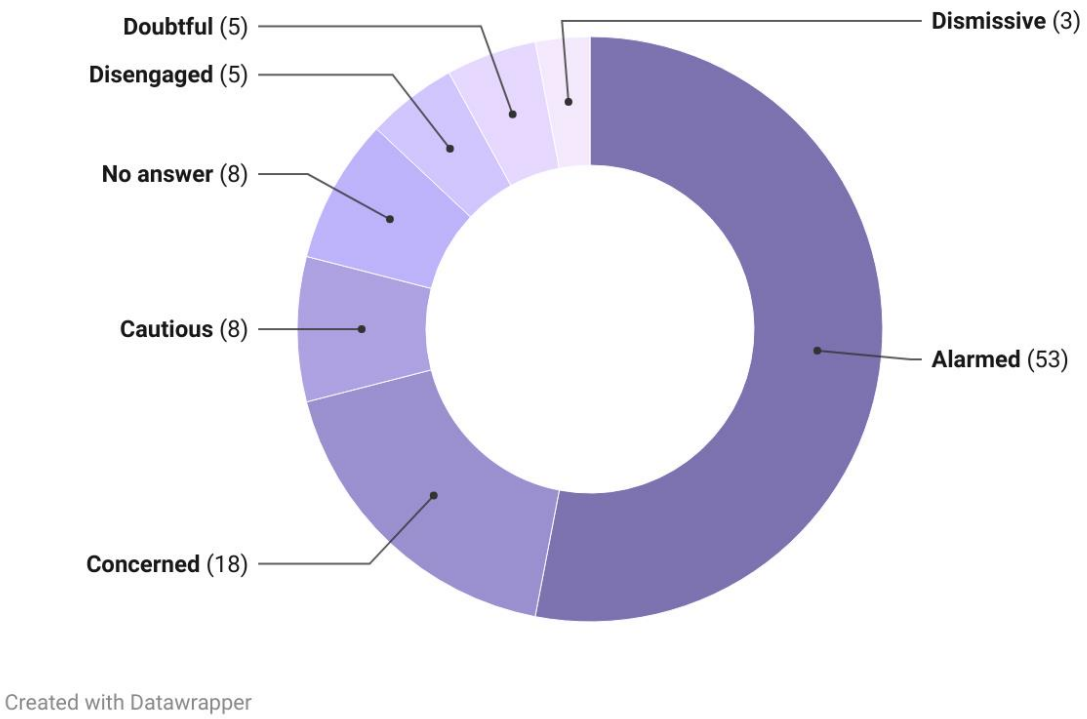
Effective climate change communication must account for the diversity of public audiences and their varying psychological profiles. Research by the Yale Program on Climate Change Communication has identified six distinct audience segments, in the USA, defined by their attitudes and engagement levels: the Alarmed, Concerned, Cautious, Disengaged, Doubtful, and Dismissive (Carman et al., 2024). The Alarmed are fully convinced of the reality and seriousness of climate change and often already take individual, consumer, or political actions to address it. The Concerned also accept that global warming is happening and view it as a serious threat, but they have not yet become personally engaged with the issue. In contrast, the Cautious, Disengaged, and Doubtful represent more ambivalent or uninformed segments – these groups range from those who

are uncertain about climate change or unprepared to accept its significance, to those who know little about it and are not actively thinking about the problem. None of these three groups is actively involved in climate action, reflecting various stages of understanding and acceptance. Finally, the Dismissive are convinced that climate change is not happening (or not a problem) and often actively oppose measures to reduce greenhouse gas emissions (Carman et al., 2024). These six audience types are used as a guide to tailor climate messaging; strategies effective for engaging the “Alarmed” or “Concerned” will differ greatly from those needed to reach “Doubtful” or “Dismissive” individuals.

2.2.2 Public Perceptions of Climate Change in Turkey

Compared to the USA, the Turkish public includes all six of these audience types, but in different proportions (see Figure 2.18). Recent international surveys show a high overall awareness and concern about climate change in Turkey. According to a 2023 Yale Program on Climate Change Communication report, more than 70% of people in Turkey believe climate change is happening and express worry about the issue (Leiserowitz et al., 2023). Furthermore, 71% of the Turkish public say that climate change is personally either “extremely” or “very” important to them (Leiserowitz et al., 2023)

Figure 2.18 *The Percentages of Six Types of Audience in Turkey*



Note. Data source of Figure ("Global Warming's Six Audiences around the World," n.d.).

These figures suggest that majority of Turkey's population falls into the "Alarmed" or "Concerned" categories of the audience spectrum. However, the other types who are doubtful about the issue should not be forgotten. Communicators need to reinforce the commitment of the already concerned majority while also educating and motivating the less engaged groups. Overall, the Turkish case reflects a population broadly aware of climate change, providing a crucial foundation upon which effective communication and engagement strategies can build.

2.2.3 Evolution of Climate Change Communication Approaches

Over the past decades, the focus of climate change communication has evolved in response to shifting public attitudes and challenges. Early efforts concentrated on conveying the scientific facts of climate change to increase public understanding. As the

issue became more important, communicators then turned to counteracting climate change skepticism. More recently, there is growing recognition that simply providing information or challenging skeptics is not sufficient; communicators are increasingly dealing with emotional and psychological responses to the climate crisis. Moser and Pike (2015) state that earlier training in climate communication centered on explaining the science and addressing denial, but now local practitioners frequently seek guidance on handling emotional distress, eco-anxiety, hopelessness, and despair in their communities. In other words, the communication paradigm has shifted from a purely cognitive, informational approach to one that also addresses the affective dimension of climate change (Moser & Pike, 2015). This evolution reflects an understanding that fear, grief, or other negative emotions related to climate change can become barriers to engagement if not properly managed.

One consequence of this shift is the need to bridge the gap between awareness and action – often referred to as the attitude–behavior gap. Even as public concern about climate change has grown, this has not always led to changes in behavior or policy support. For example, many European countries show high levels of concern about climate change, yet taking meaningful action (such as significantly cutting carbon emissions) has not taken place because it requires substantial lifestyle changes (Sippel et al., 2022). In essence, understanding the problem does not automatically lead individuals to adopt solutions. This attitude–behavior gap underscores that effective communication must go beyond informing or even convincing audiences that climate change is real; it must also motivate and empower people to alter their behaviors and support collective action. Communicators are now tasked with not only raising awareness but also addressing the psychological, social, and practical factors that inhibit action despite

concern. This insight is leading to more research into how messages can inspire personal and political action on climate issues, marking a maturation of climate communication strategies to include emotional and behavioral outcomes, not just knowledge transmission.

2.2.4 Public Engagement and Localized Communication Strategies

Broad public engagement is increasingly seen as critical to tackling climate change, requiring communication efforts that resonate both at individual and community levels. Public engagement can be viewed from two complementary perspectives: personal engagement, referring to individual cognition, attitudes, and behavior change, and civic engagement, referring to participation in collective problem-solving, policy-making, and social movements (Kumpu, 2022). Both levels are important. Kumpu (2022) emphasizes that achieving the rapid societal transformations necessary for climate mitigation – with the consent and participation of the people – demands effective communication and active public involvement. In short, without an engaged public that understands the issues and feels motivated to act, even well-designed policies or technologies may fail. Climate change communication thus must not only inform but also inspire the public, fostering a sense of shared responsibility. Agin and Karlsson (2021) note the need to focus on the construction of media messages and the processes of public communication to better reach diverse audiences. This includes careful framing of climate information, choosing language and narratives that connect with people's values and experiences, and selecting appropriate channels for different groups. A one-size-fits-all approach is ineffective given the varied audience segments and cultural contexts. Instead, localized communication approaches are encouraged. As Temple (1978) suggests global problems often must be tackled through local action and context-specific solutions (p. 7). Similarly, Günay and

Güçdemir (2022) argue that improving climate crisis communication and even turning it into a broader cultural policy will require identifying approaches, processes, methods and tools that meet the global problem on a local context (p. 1026). And besides these identifying processes, determining the scope and themes of climate messages and reporting them based on the mind frames and focal points of each target audience will enable successful communication (p. 1039). In sum, effective public engagement necessitates culturally and locally tailored communication strategies, uniting clear global messages with local relevance to stimulate both personal and collective action.

2.2.5 Emotional and Motivational Dimensions of Climate Communication

Beyond cognition and information, the emotional dimension of climate change communication has become a key factor in motivating action. Communicators and psychologists note that emotions can be powerful drivers or impediments in motivating people to respond to climate change. Fear and urgency, for example, must be balanced carefully: while emphasizing the urgency of the climate crisis is important, too much fear can backfire, leading to paralysis or despair. Thus, one communication challenge is underlining the seriousness of the threat without promoting a sense of hopelessness. Recent studies highlight the importance of eliciting constructive emotions that encourage engagement rather than apathy. Salama and Aboukoura (2018) point out that practitioners aiming to communicate climate issues effectively should recognize the crucial role of emotions in motivating action. Different emotions can have different effects; for instance, fear might grab attention but needs to be coupled with efficacy and hope to result in action, whereas feelings of hope, inspiration, or even righteous anger might directly motivate people to get involved. Therefore, communicators need to carefully consider which specific emotions to evoke in their audience to prompt the desired response

(Salama & Aboukoura, 2018). For example, messages that inspire hope by highlighting solutions and success stories can empower audiences, whereas messages that tap into moral outrage over climate injustices can power collective action.

Adding to that effective climate communication often involves storytelling and imagery that resonate emotionally. Research-based principles for public engagement underlines the significance of making climate change not just an abstract scientific fact, but a personally meaningful narrative. For instance, Sippel et al. (2022) emphasize using human stories, vivid imagery, and local examples ("connecting climate change to local issues") to reach people's hearts and minds. By framing climate change in terms of things people already care about – their families' health, their hometown's environment, their livelihoods – communicators can create empathy and concern that feel immediate rather than distant. In summary, understanding the emotional landscape of the audience and strategically invoking emotions like hope, concern, or solidarity is a crucial part of contemporary climate change communication. These motivational drivers help close the gap between knowing about climate change and feeling compelled to do something about it.

2.2.6 Barriers to Effective Climate Communication: Complexity and Uncertainty

Communicating climate change to the public is challenging due to inherent barriers. One major barrier is the complexity of the issue. Climate science involves complex systems, huge amounts of data, and probabilistic forecasts, all of which can overwhelm or confuse non-experts. Moser and Pike (2015) note that climate change embodies a list of communication difficulties: its urgency and enormous scale, its scientific complexity, and the uncertainties in predicting specific outcomes all make it hard to convey a simple, compelling message. They describe climate change as one of the

most difficult global challenges to communicate and motivate action on, in part because many of its causes (e.g. invisible greenhouse gases) are not directly observable, and its effects are separated from their causes by large distances and longtime lags (Moser & Pike, 2015). The fact that climate change is a global, systemic problem with impacts that are felt over decades or centuries means it lacks the immediacy that typically powers public response. People find it hard to connect emotionally to an issue that is often framed in abstract statistics or distant future scenarios.

Another barrier closely related to complexity is scientific uncertainty. While the fundamental science of climate change is well-established, predictions of specific impacts (like the exact timing and magnitude of local climate effects) carry uncertainties. Moser (2010) points out that climate change is not entirely understood and never completely predictable, which results in lingering uncertainty in climate information. This uncertainty can be misinterpreted by the public as a sign of unreliability or can undermine the credibility of climate science. Moreover, Li et al. (2022) highlight that the problem is caused by multiple layers of complexity in the climate system: cause-and-effect relationships are often separated by vast distances and times (for example, emissions from one country affecting weather patterns in another, decades later), and the future under climate change involves unfamiliar and unpredictable conditions. Additionally, different groups of people interpret climate information through different worldviews, which can alter their acceptance of the science (Li et al., 2022). All these factors make it challenging to create messages that are both accurate and easily understood. Johansson et al. (2010) state that information on climate change is inherently complex in nature, which stands as a fundamental obstacle to public comprehension. The complexity and abstractness of climate change lead to further communication challenges.

Message framing is also difficult: communicators must simplify the problem to make it understandable, yet not oversimplify to the point of downplaying the seriousness. Agin and Karlsson (2021) describe this as a core dilemma for climate communicators – how to simplfy a complex, nuanced scientific issue into clear terms that reduce misunderstandings and skepticism, without dismissing the severity of its consequences. Prior research has identified several consistent issues that negatively affect climate communication, including a lack of immediacy (the threat doesn't always feel urgent or present), inappropriate framing of messages, the sheer complexity of the issue, and prevailing social norms or cultural values that lead people to tune out climate messages (Axon et al., 2018; Moser & Dilling, 2011; van Riper et al., 2020; Li et al., 2022). For example, if climate change is framed as a distant environmental problem, it may fail to engage those who would respond more to health or economic frames. All these barriers – complexity, uncertainty and psychological distance interact in complex ways. They prove why climate change is widely regarded as a wicked problem not just scientifically, but also in terms of communication.

2.2.7 Bridging the Science–Public Gap: The Need for Intermediaries and Clarity

Given the challenges outlined above, a critical task is to bridge the gap between scientific knowledge and public understanding. One issue is that the language of climate science can be highly technical, while the public needs clear and relevant information. As explained by Kurnaz (2022) climate science has "terabytes of data" accumulated over years of research, yet many ordinary citizens are left asking, "So what should I do?" (p. 224). This highlights a disconnect between the language of data producers (scientists) and the language of end users (the public). Kurnaz (2022) emphasizes that these two groups effectively speak different languages – "science language" vs. everyday language – and

therefore require translation. At present, there are very few intermediaries or knowledge brokers whose role is to translate climate data into practical guidance for the public (Kurnaz, 2022). The absence of such mediators means much climate knowledge remains locked in scientific circles and fails to inform public decision-making or behavior. Major scientific reports illustrate this gap. For instance, the comprehensive assessments by the Intergovernmental Panel on Climate Change (IPCC) are written by and for scientists and policymakers, making them dense and difficult for the general public to digest. Agin and Karlsson (2021) note that IPCC reports, while authoritative, are hard for laypeople to understand and draw meaning from (p. 431). This is not a flaw in the science itself but is a communication problem. The public often struggles to extract personal relevance or actionable information from technical documents. As a result, even critical findings may not reach public consciousness or drive behavior change. To bridge these gaps, communicators call for clearer, more accessible messaging and the use of intermediaries who can interpret climate information for non-specialists. Scientists who are used to speaking in technical terms may need support from communication professionals to reframe their messages. Kurnaz (2022) argues that because scientists often speak in jargon that "is not always understood," there is a pressing need for definite, clear, and comprehensible messages about climate change (p. 205). The goal is to present climate information in plain language, with concrete examples and relevance to everyday life. In practice, bridging the gap might include creating infographics that summarize key data.

2.2.8 Role of Information Design and Visualization in Climate Communication

One promising approach to overcoming communication barriers is the use of effective information design and data visualization. Visual communication can help simplify complex climate data into more intuitive forms, making the information

accessible to broader audiences. Researchers have found that well-designed visuals – such as charts, maps, and infographics – can bridge the gap between scientific complexity and public understanding by presenting data in a clear and engaging manner. For example, Christel et al. (2018) identify the communication of complex scientific information as a major challenge in providing climate services to decision-makers in industry. Their work suggests that design techniques and information visualization can be valuable solutions to convey such information (p. 113). In practice, this means translating climate model outputs or risk assessments into visual formats that highlight key trends and implications, rather than requiring the audience to deal with technical text or tables. An effective visual design can simplify without overly dumbing down the content: it can use color, layout, and interactive elements to guide viewers through data, emphasize the most important insights, and relate them to something tangible (such as showing sea-level rise affecting a familiar local landmark). Information design also plays a crucial role in storytelling. A visual timeline of climate impacts, a comparison chart of emissions scenarios, or a personal carbon footprint calculator with interactive visuals can all make the climate issue more concrete.

In the age of digital media, infographics and data-driven animations about climate change circulate widely on social networks, potentially reaching audiences who would not read a scientific report. Thus, incorporating principles of graphic design and human-computer interaction into climate communication efforts can significantly enhance their effectiveness. In summary, information visualization serves as a critical tool to overcome some of the inherent difficulties in climate communication: it helps simplify complexity, overcome language barriers, and make data emotionally resonant. This dissertation, in

particular, builds on the premise that systematically evaluating and improving climate change visuals can further enhance public engagement and understanding.

2.2.9 Principles and Best Practices for Effective Climate Change Communication

The interdisciplinary field of climate communication includes set of best practices and various guides aimed at improving public engagement. For example, Sippel et al. (2022), propose ten key principles for effective climate change communication, which they group into three main categories. The first category, "How to open the door," focuses on initial engagement strategies: it emphasizes connecting with people by understanding their values and concerns, providing information from trusted sources, and testing communication approaches on a small scale before a major publication. This reflects the idea that the first impression matters – communicators should start by finding common ground with the audience and ensuring the information is seen as credible and reliable. Establishing trust at this stage is crucial (more on trust in the next section), as is tailoring the entry point of the conversation to what the audience cares about (for example, discussing air quality or jobs in the context of climate solutions if those resonate more than abstract climate data). The second category, "How to reach people's hearts and minds," highlights the importance of making climate change personally relevant and emotionally compelling. Key principles here include connecting climate change to local issues and everyday experiences, using narratives and storytelling rather than just dry facts, and using powerful imagery to make the abstract concrete (Sippel et al., 2022). This set of principles aligns with the earlier discussion on emotional and motivational dimensions: people are more likely to care about climate change if they see how it affects things they love or if they can picture the problem and its solutions concretely. Storytelling might involve sharing testimonies of individuals impacted by extreme

weather, or positive stories of communities transitioning to renewable energy. Visual imagery could be as simple as before-and-after photos of a receding glacier or as creative as art installations representing carbon emissions – anything that creates a mental picture to accompany the data. The third category, "How to turn concern into action," deals with moving the audience from passive concern to active participation. Sippel et al. (2022) stress principles such as highlighting solutions (so people don't feel stuck with an insoluble problem), creating opportunities for interaction and dialogue (so the public can ask questions, share input, or get involved in a hands-on way), and framing climate-friendly actions as a means of creating social belonging and community. The idea of social belonging is particularly important: if taking action on climate change (like joining a local environmental group, or even just adopting sustainable behaviors) is seen as something that connects people with others and contributes to a positive community identity, individuals may be more inclined to do it. This principle taps into humans' social nature; climate action should be portrayed not as a solitary burden but as a collective endeavor that can be fulfilling and even enjoyable. In summary, these ten principles collectively underscore a comprehensive approach – from building initial trust and relevance, to engaging emotions and local context, to empowering action and participation. They serve as a guide for practitioners to design communication campaigns that not only inform but also inspire sustained public engagement with climate change.

2.2.10 Trust and Communicator Credibility

Underlying all effective communication efforts is the element of trust. The influence of any climate message depends heavily on the audience's trust in the source or messenger (Fielding et al., 2020). If the communicator – be it a scientist, government agency, NGO, or a corporation – is perceived as credible and having integrity, the public

is more likely to listen to and be persuaded by their message. Conversely, if trust is lacking, even accurate information may be dismissed. Fielding et al. (2020) note that the impact of most messages will be mediated by the level of trust people have in whoever is delivering the message. This is why messengers are often as important as the message itself in climate communication. For instance, community leaders, doctors, or farmers might be more trusted by certain local audiences on climate issues than distant politicians or scientists, even if they convey similar information. Building trust involves transparency, honesty about uncertainties and risks, and consistency over time. Communicators should avoid exaggeration or alarmism that could later be discredited, as that can harm credibility permanently. Instead, being forthcoming about what is known and unknown, and why certain actions are recommended, helps establish an honest dialogue. Trust is also reinforced by demonstrating empathy and understanding of the audience's perspective – people need to feel that communicators are not talking at them but rather with them, taking their concerns seriously. As noted, one of Sippel et al.'s (2022) first principles are to support trustworthy information; this includes fact-checking, using reliable data, and possibly third-party endorsements (such as independent experts presenting their views of a campaign's information). In sum, trust is the currency of effective communication. Any strategy to engage the public on climate change must consider not just the content of the message, but who delivers it and how to cultivate credibility and good intentions in the eyes of the audience.

2.2.11 Climate Communication Initiatives, Public Awareness and Green PR in Turkey

Public education and awareness-raising campaigns are a common strategy in climate change communication, and Turkey has seen a number of such initiatives, particularly led by corporations and civil society as part of social responsibility efforts.

One typical approach is informational campaigns that aim to increase knowledge and visibility of climate issues. For example, a Turkish energy company might launch a communication campaign informing the public about sustainable energy production methods, with the goal of guiding consumers toward more environmentally friendly consumption habits (Rençber & Arklan, 2023, p. 17). By highlighting how individuals can save electricity or switch to cleaner energy sources, the company uses information provision as a tool to influence behavior (Günay & Güçdemir, 2022). This kind of educational messaging often serves as a first step in broader engagement strategies, seeking to create awareness and concern as first steps to action.

In Turkey, many early climate communication efforts took the form of corporate social responsibility (CSR) campaigns or public service announcements. Starting around 2009 and gaining momentum after 2017, numerous campaigns were launched by businesses, NGOs, and government agencies with the aim of drawing attention to climate change and building public awareness (Günay & Güçdemir, 2022). Analyses of these campaigns indicate that their primary objectives were to put climate change on the public agenda and to inform citizens about the issue (e.g., explaining what climate change is and why it matters).

The public may be aware that human activities cause environmental problems and even acknowledge observable changes (like more frequent floods or heatwaves), yet people still need guidance and information on how to respond and what can be done to mitigate the crisis (Kurnaz, 2022). In Turkey, as elsewhere, simply knowing about climate change does not automatically equip citizens with solutions. Therefore, many communication initiatives stress practical information: advising on actions such as using public transport, reducing meat consumption, supporting reforestation, or preparing for

emergencies. By informing society about actionable responses, these campaigns attempt to bridge the gap between awareness and engagement.

Besides NGOs, organizations—ranging from businesses to government bodies—are key players in climate change communication, often through green public relations (green PR). Green PR refers to communication efforts by institutions that center on environmental issues as part of their corporate social responsibility and sustainability objectives. It involves not only promoting a company's eco-friendly activities or initiatives but also engaging with the public on environmental values and practices (Rençber & Arklan, 2023, p.10). In essence, green PR is an organization's attempt to align itself with the growing public demand for environmental awareness and to improve its image by highlighting contributions to environmental sustainability. An example might be a manufacturing company running a campaign about its new carbon-neutral operations or a bank publicizing its investments in renewable energy projects. These communications aim to inform stakeholders about the company's environmental actions, hoping to earn public trust. The rise of green PR is driven in large part by external motivations – notably, consumer expectations and public pressure. As Erbaşlar (2012) discusses, in modern society, companies are seen as socio-economic actors that are expected to respond to societal concerns, including environmental ones (p. 95). With increasing awareness of environmental issues, consumers and citizens are demanding more accountability and action from businesses regarding climate change and ecological impact. Surveys and market research have shown that consumers are more likely to support or trust brands that demonstrate environmental responsibility. Many consumers, especially as their standard of living improves, no longer limit their expectations to product quality or personal benefits; they also look at a company's broader social and

environmental performance (Rençber & Arklan, 2023, p.10). They expect businesses to take responsibility in areas like environmental protection, public health, and workers' rights, not just profit-making (Erbaşlar, 2012; Rençber & Arklan, 2023).

In other words, public demand becomes a source of motivation: companies may fear reputational damage or loss of market share if they are seen as doing nothing about climate change, thereby prompting them to communicate and improve their environmental efforts. Green PR is not without its challenges and skeptics, however. There is the risk of greenwashing, where organizations might communicate more about their green intentions than actual impacts, or selectively highlight positive aspects while ignoring negative ones (Yazıcı, 2023, p. 150). This can lead to public cynicism if audiences feel misled. Therefore, credibility (as discussed earlier) is crucial; communications should be backed by transparent reporting and substantive action. Done sincerely, green PR can play a constructive role in climate communication by leveraging corporate resources and marketing reach to inform and engage the public on sustainability issues. It also reflects a broader trend where the lines between public sector, private sector, and civil society roles in climate advocacy are blurring. Businesses are increasingly stepping into advocacy and education roles, partnering with NGOs or campaigns, which can amplify climate messages to wider audiences. In the context of Turkey, Borusan Holding has initiated the establishment of Yuvam Dünya (an NGO with a focus on climate change) and has been carrying out various activities through and together with this organization.

2.2.12 Traditional Media vs. New Media in Climate Communication

The media landscape is a critical factor in how climate change information disseminates through society. Traditional media (such as newspapers, television, and

radio) and new media (such as social media platforms, blogs, and online news) each have distinct roles, strengths, and weaknesses in climate communication. According to agenda-setting theory in mass communication, increased media coverage of an issue elevates its importance in the public's mind, which can in turn lead to greater public engagement or pressure for action (McCombs, 2005; McCombs & Shaw, 1993). In the context of climate change, this means that the more prominently and frequently climate issues appear in the media, the more likely the public is to view climate change as urgent and worthy of action. Empirical studies support this notion: for example, Wu et al. (2022) cite agenda-setting theory in suggesting that extensive media attention to climate change can stimulate higher public participation in climate-related activities or policy support. However, the content and framing of media coverage are just as important as volume. Research has pointed out that mainstream news media have not always provided an accurate or sufficient portrayal of the climate crisis. In fact, a lack of a sustained sense of urgency among the general public and political elites has been attributed in part to media coverage that falls short. Many mainstream outlets historically under-report climate change or present it in diluted terms, failing to convey the gravity of the consequences, the most effective solutions, or the overwhelming scientific consensus on human-caused climate change (Feldman et al., 2017; Moser, 2016; Petersen et al., 2019; Bogert et al., 2023). This can result from various factors: the complexity of the topic, perceived audience fatigue, editorial biases, or the tendency to give disproportionate attention to climate skeptics in the name of balance. The outcome is that audiences of traditional media might not get the full story or the urgency, potentially contributing to complacency or misunderstanding.

Different types of media also differ in scope and credibility. For example, in China, National-level (central) media outlets often provide more authoritative and in-

depth reporting on climate change. They have the resources to cover international climate conferences, scientific developments, and high-level policy debates, offering what Wu et al. (2022) describe as "higher-dimensional information" that explains climate phenomena and trends. Local media, on the other hand, tend to focus on climate news that is directly relevant to their region – for example, covering a local drought, a community solar project, or a city's climate action plan. Such local reporting can make the issue more immediate to residents by showing local impacts and initiatives (Wu et al., 2022, p. 18). Both central and local media generally follow journalistic standards that lend them higher credibility in the eyes of the public. By contrast, social media can cover a wider range of climate content, from global viral videos to niche discussions, but information on social networks is often seen as less credible (Wu et al., 2022, p. 2). On social media, content is user-generated and not always fact-checked, which means misinformation can spread alongside accurate information. Despite this, social media have enormous reach and can engage audiences through shares, comments, and communities of interest, something traditional media do not provide. One of the biggest changes in recent decades is how interactive and networked communication has become through new media. Social media platforms (Facebook, Twitter (X), Instagram, TikTok, YouTube, etc.) enable individuals to connect with others around the world and share information instantly, bypassing traditional media outlets. This has democratized climate communication to a large extent. A teenager can create a climate-awareness video on TikTok that gains millions of views, or community activists can organize via Facebook groups. Wu et al. (2022) note that social media has expanded the traditional structure and logic of media communication: instead of one-way broadcasting, there is now a web of many-to-many communication (p. 17). This means climate change discussions can happen in real-time, with users not

only consuming information but also participating in it – by commenting, questioning, providing local observations, or contributing personal narratives. Additionally, unlike the limited opportunities for engagement with traditional media, social media's design inherently encourages users to react and interact. The result is that many individuals now obtain climate information through a mix of channels. Wu et al. (2022) found that people are in fact most inclined to use social media to get climate change information, compared to other channels. Social media's immediacy and the personal networks through which information flows make it a convenient source. However, interestingly, Wu et al. (2022) also found that traditional central media use had the highest correlation with actual climate communication behaviors (e.g., talking about climate change, supporting policies). This suggests that while social media is popular for information, mainstream media coverage might still be a stronger driver of behavior – perhaps due to the depth and credibility of the information provided by established news sources. It could also indicate that those who follow climate news on traditional media are particularly motivated or attentive individuals. Given the complementary roles of different media, experts recommend a multimedia approach to climate communication. Governments and environmental organizations are urged to utilize both traditional outlets and new digital platforms to promote pro-environmental values and ensure climate change is conveyed prominently and effectively (Wu et al., 2022, p.22). For example, a public awareness campaign might simultaneously publish ads in newspapers (to reach policymakers and older audiences), air TV/radio spots (to reach a broad public), and launch social media challenges or hashtags (to engage youth and online communities). Importantly, social media campaigns have practical advantages: they can be low-cost compared to large media buys on television, and they allow targeting specific demographics with tailored

content (Wu et al., 2022, p. 3). However, the trade-off is the need to carefully manage the accuracy and clarity of messages in an environment where misinformation can circulate.

2.2.13 Social Media and User-Generated Content: Potential and Challenges

Social media and other user-generated content platforms offer significant potential for enhancing climate change messaging, but they also come with limitations and challenges. On the positive side, social media can personalize the issue of climate change. Instead of abstract graphs of global temperature, a Facebook post might show how a community experiences changes in the growing season, or a Twitter thread might connect climate data to a recent flood in a town. This act of personalizing and concretizing climate change helps bring the concept closer to individuals who have not yet felt direct impacts (Parry et al., 2022, p.31). Parry et al. (2022) describe social media as a useful tool to bridge the gap between abstract global phenomena and personal experience, similarly Anderson (2017) state that digital storytelling can make climate change more relatable. For instance, hashtags like #ClimateStory or #FridaysForFuture allow people around the world to share their individual experiences or actions, creating a collage of narratives that illustrate the many faces of climate change. Such content can evoke empathy and a sense of global community. Social media's speed is high and reach is wide. Institutions and individuals alike can disseminate information rapidly. A company or government agency can quickly announce new environmental initiatives on Twitter (X) or Instagram, reaching a wide audience without the delays of press releases and news cycles (Günay & Güçdemir, 2022).

In Turkey, as in many countries, organizations have capitalized on platforms like Instagram and YouTube to publicize their environmental projects, events, and campaigns in near real-time, thereby gaining support and engagement from a broad audience (Günay

& Güçdemir, 2022). Social networks also allow communicators to tap into peer-to-peer influence: when people see their friends or family talking about climate change or sharing eco-friendly actions, it can have a strong persuasive effect due to social proof and trust in one's peers. This viral potential means a compelling climate message or visual can spread far beyond its original context. Moreover, user-generated content (UGC) – content created by everyday users rather than professional sources – has given rise to a diverse information ecosystem on climate change. Blogs, podcasts, YouTube channels, and grassroots campaigns contribute to the dialogue. This democratization means that voices from the global youth movement, indigenous communities, or local activists can gain prominence and influence discourse, rather than only scientists and politicians. It also allows for a diversity of formats and tones, from serious analytical explainer videos to humorous memes about renewable energy. Engaging content can thus reach different subsets of the public who might not respond to traditional messaging. Some research findings challenge the assumption that user-driven content leads to misinformation or confusion. In fact, a meta-analysis by Bogert et al. (2023) found that overall, consuming climate information through user-generated media correlates with stronger belief in the scientific consensus on anthropogenic climate change, compared to consuming information through more centralized and controlled media (p. 17). In other words, people who rely on sources like social media, forums, or independent blogs for climate information tended, on average, to be more aligned with climate science than those consuming mainly traditional media content. Additionally, using new media was associated with a slightly higher likelihood of having opinions in line with the scientific consensus (p. 15). These findings suggest that, despite concerns, digital and social media may be playing a constructive role in spreading climate awareness and pro-climate

attitudes among the public. However, the landscape of social media and UGC is not without pitfalls.

A major concern is the quality control of information. Anyone can post anything, which means false or misleading claims about climate change can spread quickly if they resonate or if they are amplified by algorithms. Climate communicators therefore must compete not only with ignorance, but sometimes with active disinformation. The fragmented nature of online information also means audiences can self-select into echo chambers. For example, someone inclined to doubt climate change can find online communities or YouTube videos that reinforce their skepticism, insulating them from mainstream scientific views. This polarization of information sources is a challenge that the climate communication field is still dealing with. Another issue is that research on the impact of social media in climate communication is still emerging. Agin and Karlsson (2021) point out that a large portion of climate communication studies to date have focused on traditional media, and even within social media, they often focus narrowly (for instance, many studies look only at Twitter (X), due to data accessibility). As a result, we know less about newer platforms like TikTok or Snapchat, or search engines and private messaging apps, which also play roles in how people get information. Similarly, Bogert et al. (2023) state the need for further research, questioning whether the correlation between social media use and pro-climate beliefs is because already-informed individuals seek out more climate content online, or because online sources are actually better at conveying climate information effectively, despite the presence of some misinformation (p. 17). They call for studies that can untangle these factors and for expanding research to more countries and platforms, as much of what we know comes from a limited set of mostly Western contexts (Bogert et al., 2023). In light of both the promise and challenges

of social media, the consensus among experts is that climate communication should actively engage with these platforms, but in a strategic manner. This means creating shareable, accurate content; using influencers or respected figures to disseminate messages; actively countering misinformation with fact-checks; and fostering online communities that encourage learning and action. Social media should be seen as a partner to traditional outreach, not a replacement, and strategies should be adaptive as platforms evolve. Ultimately, as Bogert et al. (2023) conclude, future communication efforts and research should pay close attention to user-generated media, as these channels are becoming increasingly central to how the public, especially younger generations, learn about and discuss science issues like climate change.

2.2.14 Summary of Chapter

In summary, the field of climate change communication has advanced to recognize numerous factors that influence public engagement, from audience segmentation and cultural context to emotional appeal and message delivery. Communicating climate change effectively requires not only conveying scientific facts, but also building trust, referring to diverse values, simplifying complexity without sacrificing accuracy, and empowering audiences to move from awareness to action. It is a complicated challenge: one must address informational barriers (translating science into plain language and visuals), psychological barriers (overcoming fear, apathy, or despair), and societal barriers (navigating polarization and misinformation). The need for effective public engagement is clear, as meaningful climate action depends on social consensus and participation. This has led to best-practice principles that emphasize local relevance, storytelling, solution-oriented framing, and interactive dialogue. Within this landscape, information design and visualization emerge as crucial tools. Effective visual

communication can present complex climate data in a simplified easy to grasp ways, thereby enhancing understanding. Given that climate change is often invisible or abstract, visuals can make it tangible. Whether through maps of changing flood zones, graphs of emissions trajectories, or infographics of carbon footprints, visual tools help out the cognitive challenges identified in this background. They also have the potential to engage emotions and prompt discussions on social media, bridging traditional and new media environments. As this dissertation will explore, establishing a conceptual framework for evaluating such climate visuals can significantly contribute to improving how we ensure their effectiveness. By identifying key criteria for successful climate change visualizations, we can guide the creation of communication materials that better inform, engage, and motivate the public.

3. METHODOLOGY

The methodology of this study consists of three consecutive stages: In the first stage, exploratory interviews were conducted with professional graphic designers who designed information visualizations as part of their work. The findings in the initial stage are used to refine the research questions further and help to form the research design of the second stage. In the second stage, workshops were conducted with experts on the subject: researchers, NGOs on climate change and professional designers. The aim was to reach all relevant types of expertise which form the core of information visualizations for the climate crisis. The third stage includes a survey conducted with expert designers to examine the relationship between the identified Infovis measures and the overarching goals of climate change communication. The detailed explanation of the methodology is provided in the following sections.

3.1 First Stage: Exploratory Interviews with Experts

The aim of the exploratory interviews was to understand the underlying measures that are employed in information visualizations by professional designers. (See Figure A.1 through Figure A.14 and Table A.1 through Table A.6 in Appendix A for interview questions, initial codes and information visualization examples shown to the participants)

Three participants were interviewed: Participant 1 (referred to as d1) is a freelance graphic designer, data visualization expert and an academic. Participant 1 has completed their Ph.D. focusing on an undergraduate level course structure designed for teaching data visualization to students enrolled in graphic design departments. Participant 2 (referred to as d2) is a freelance graphic designer and an illustrator who also creates infographics

for social media. Participant 3 (referred to as d3) is a graphic designer working as a UX/UI expert at a bank whose work involves (financial) information visualization.

The interviews were conducted online over Zoom (d1 on May 19th, 2022; d2 and d3 June 6th, 2022). The interview with d1 lasted for 60 minutes, the interview with d2 lasted for 45 minutes and the interview with d3 lasted for 50 minutes. Each interview session was video and audio recorded and transcribed manually for analysis. The interviews were semi-structured. Questions followed a funnel approach, where they changed from general to detailed. The following table (see Table 3.1) presents the exploratory interview question in Part 1 of the study.

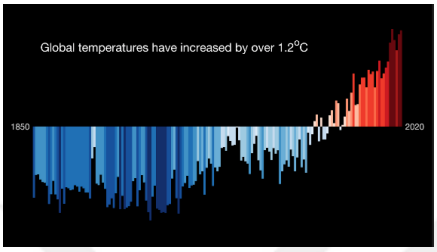
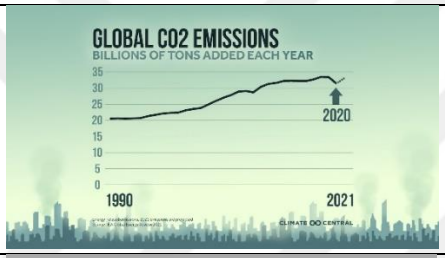
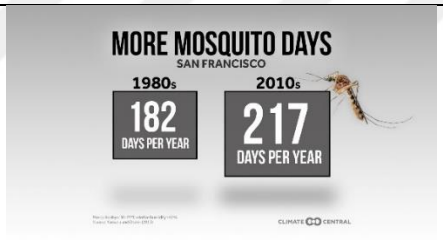
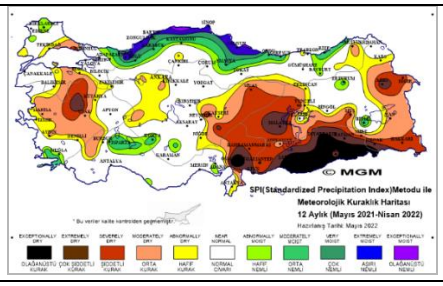
Table 3.1 *Interview Questions for Part 1*

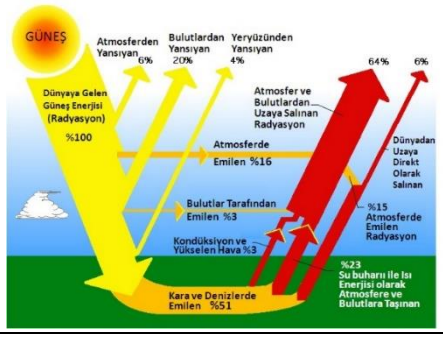
PART 1		
	Questions asked	**Translation of the question in English**
1	*Bir bilgi görselleştirmesini "iyi" yapan nedir?*	What makes an information visualization "good"?
2	*Bir bilgi görselleştirmesini etkili kılan nedir?*	What makes an information visualization effective?
3	*Belirli bir hedef kitle (halk) veya uzman olmayan kişiler için tasarım yaparken, bilgi görselleştirmenin hangi yönü öne çıkar?*	When designing for an intended audience or lay people what aspect of information visualization becomes prominent?
4	*Bilgi görselleştirme için tasarımın önemi/rolü nedir?*	What is the significance of design for information visualization?
5	*Bilgi görselleştirmede etki yaratmak için hangi tasarım öğeleri ve özellikleri önemlidir?*	Which design elements and properties are significant for creating impact in information visualization?

Towards the end of each interview, in Part 2, participants were shown 6 examples of information visualizations on the climate crisis context. The images were shared over Zoom. They were asked to rate the measures for each visualization and provide additional comments. The interviewer took digital notes on the answers of the participants. The 6 images were selected from a collection of 22 information visualizations on climate change and they were collected from social media. The participants elaborated the concepts they mentioned during the interviews by the help of those information visualization examples

(see Table 3.2 for images shown in Part 2 and see Table 3.3 for the table used to collect ratings and notes).

Table 3.2 *Images Shown in Part 2 of the Exploratory Interview*

PART 2		
	Image (information visualization)	**The reason behind choosing this image**
1		The visualization is a bar chart that includes various colors and there is not much text in it.
2		The visualization is a line chart with an illustrative background.
3		The visualization is a proportional area chart that includes a photograph.
4		The visualization is a line chart with more layers of data and includes a logo embedded at the background.
5		The visualization is a choropleth map with a wide range of colors for different variables.

PART 2		
	Image (information visualization)	**The reason behind choosing this image**
6		The visualization is a variation of a Sankey Diagram and includes a lot of text and colors. There is also a subtle illustration on the left side.

All images are in public domain, for references please see Appendix A (Figure A.9 through Figure A.14).

Table 3.3 *Table Used to Collect Ratings and Notes in Part 2*

	Not present……. somehow present….. totally present					
Infovis Measures (English – Turkish)	**1**	**2**	**3**	**4**	**5**	**Comments**
Memorability - *akılda kalıcılık*						
Comprehension -*kavranabilirlik*						
Accuracy - *kesinlik*						
Efficiency - *verimlilik*						
Utility - *yararlılık*						
Clarity - *netlik*						
Speed - *anlaşılma hızı*						
Soundness - *doğruluk*						
Engagement - *ilgi çekicilik*						
Enjoyment - *eğlenceli*						
Attractiveness - *estetik olması*						

Finally, participants were asked to select the three most important measures, and they could suggest a new measure if they have found necessary.

In the methodological sense, the exploratory study provided input for the following stage in terms of research design. Firstly, the information visualization material used in the Part 2 of the interviews were selected with a relatively intuitive approach of

the researcher: the information visualization examples varied according to the design style but not according to the data, the publication medium, the data source (Table 3.2). This created problems in the analysis of the Part 2 of the interviews. Secondly, the number of examples in the material sample turned out to be inadequate to reach reliable conclusions, although the number were intentionally kept small for practical purposes, i.e. not to tire the participants.

For the second stage of this research study, the material was chosen with a more specific criteria and size of the material sample was increased as much as possible so that the participants were free to choose the images, they found necessary: i.e., the ones that were the best visual representations of the concepts they expressed in words during previous sessions.

The research questions were refined for the second stage, the workshops. The funnel approach was continued in the workshops' research design.

3.2 Second Stage: Workshops with Experts

Five workshops were conducted to explore critical measures for the climate crisis information visualizations. Workshops allow interactions among participants, creating a collaborative space for shared meaning-making. These discussions generate information and insights that would be difficult to get through individual responses alone.

The formation of the groups was made according to the relationship of participants to the subject matter. The first group consisted of experts involved in teaching design, information visualization, and climate change. The second group included activists who are trying to mobilize society to take action on the climate. The third group consisted of professional designers who are responsible for creating and delivering information

visualizations to the public. This format enabled a variety of perspectives and the topic to be fully explored.

3.2.1 Workshop Participant Selection

Workshop 1: Eight experts participated in the first workshop. For detailed information on their expertise please see Table 3.4.

Table 3.4 *Participants of the Workshop 1*

Participants of Workshop 1		
Participant	**Expertise**	**Additional information**
1	Data literacy expert	One of the founders of Data Literacy Society (Istanbul) and has a doctorate degree in media communication studies.
2	Assistant professor in the Department of Media and Visual Communication specialized in communication	Designed a course on creating animations for climate change communication.
3	Senior specialist	Leader at the Sustainability Center of the university
4	Specialist / Architect	Specialist at the Sustainability Center of the university
5	Associate professor in graphic design	Teaches courses on illustration and infographics
6	Full-time instructor at the Department of Communication Design	Previous experience in art direction and UI design
7	Part-time instructor in graphic design	Also works as a free-lance illustrator and creates infographics
8	Part-time instructor in graphic design	Also works as a freelance graphic designer and designs corporate annual reports including data visualizations

These experts were reached through emails, and they agreed to join the workshop in person. The group was hosted at Özyeğin University, and the workshop was carried out 5 hours.

Workshop 2: The participants were two graphic designers with 18 to 20 years of experience. One of the designers works for a graphic design agency and occasionally creates information visualizations. The other designer works freelance and designs infographics for clients. The participants had references from participants of Workshop 1. Since one of the participants lives in another city, workshop was carried out on Zoom

with the aid of Miro App for showing visuals and taking notes. They study lasted for 90 minutes.

Workshop 3: Two graphic designers (with 20 years and 8 years of expertise) from an award-winning graphic design agency. The agency has won awards for their annual report designs for *Gübretaş* in 2019 and 2020 with their illustrative and innovative design concepts including many information visualizations. The designers were reached through emails and preferred to join in the workshop online since they work remotely. The study lasted for 100 minutes.

Workshop 4: Participants were from Greenpeace Turkey (an activist and a communications expert). The Greenpeace activist is based on the Greenpeace ship Arctic Sunrise, travels constantly was difficult to get in contact with. The participants were reached through email and WhatsApp, and they joined in the workshop through Zoom but the activist was only able to join through the mobile phone and had limited access to Miro. The study lasted for 90 minutes, for the last 10 minutes the Greenpeace activist had problems with phone reception.

Workshop 5: Participants were a communications specialist and a social media specialist from *Yuvam Dünya* (an Istanbul based NGO that aims to transform all segments of society in the context of the climate crisis). These participants were reached through emails were hard to get in touch with because of their very busy work schedules. Since they were working remotely, this group also attended the workshop online through Zoom and Miro. The study lasted for 90 minutes.

In short, the first workshop aimed to include all the disciplines that are relevant to information visualization in climate change. It provided a general overview on the subject. On the other hand, after the analysis of this first workshop, it was seen that more

focused discussions were needed to delve deeper into subtleties of information visualization measures. Therefore, the rest of the workshops were composed of the experts from similar domains. The first workshop was conducted face-to-face whereas the second, third, fourth and fifth workshop studies were conducted online over Zoom with the aid of Miro application to talk on information visualization material. See Figure B.1 through Figure B.8 in Appendix B for images from the conducted workshops.

3.2.2 Workshop Protocol

The workshops were carried out in three consecutive sessions: In Session 1, all the participants were asked to individually think about a question on how to communicate climate change to the public. After a few minutes, they were asked to join in a free discussion on the topic. The discussion continued for approximately 45 minutes in Workshop 1 and 25 minutes in all the other workshops. The moderator wrote down keywords during discussions to share it in the following session.

In Session 2, the moderator shared the noted keywords from Session 1. In addition to the noted keywords, information visualization measures derived from the literature were presented to participants with short definitions of each measure. The participants reviewed noted keywords to make sure there is no misunderstanding by the moderator. Also, they reviewed the noted keywords and literature driven measures, and contributed with additional measures they found significant for the topic of climate change. There was no time limit for this session.

In Session 3, participants were presented with a sample of 104 information visualizations which were hung on a wall or presented over Miro application. They were asked to elaborate on the in vivo keywords and literature driven measures by selecting relevant information visualization examples among the 104 examples. They were

requested to explain why they think that example presents the measure. There was no time limit for this session. The workshop protocol is summarized in Table 3.5.

Table 3.5 *Workshop Protocol*

Session 1 – Free discussion			
	Questions asked	**Translation of the question in English**	**Role of the researcher**
1	*İklim değişikliği konusunda halka ne anlatılmalı ve nasıl anlatılmalı?*	What should be told to the public about climate change and how should it be told?	The researcher takes notes of keywords to use in Session 2
2	*İklim değişikliği konusunda infovis (bilgi görselleştirme, infografik) yaparken nelere dikkat etmeli? Kriterleri nelerdir?*	What should be considered when making infovis (information visualization, infographic) on climate change? What are the criteria?	
Session 2 – Discussion on Measures			
3	12 measures from literature are presented in both Turkish and English. The list of measures are: Credibility, clarity, engagement, aesthetics, memorability, utility, comprehension, speed, saliency, efficiency, accuracy, enjoyment.		The researcher explains each measure and provides English-Turkish translations for clarification.
	Questions asked	**Translation of the question in English**	**Role of the researcher**
4	*Literatürdeki ölçütlere ekleyeceğiniz veya değiştireceğiniz ölçütler var mı?*	Are there any measures you would add or change to those in the literature?	Researcher writes down all the measures listed by participants. Also adds keywords from Session 1. These are hung on the wall or written on Miro.
Session 3 – Matching of visualizations			
			Role of the researcher
5	104 information visualizations are presented	Participants look through each visualization.	These are hung on the wall or presented on Miro.
6	Visualizations are selected for each measure.	Participants select visualizations that best exemplify each measure that has been noted in Session 2.	Researchers encourage participants to select visualizations for all measures pointed out in Session 2.
7	Participants are asked to explain why they have chosen that specific visualization for the measure.	Participants verbally explain their comments on Zoom or they write notes on the papers in face-to-face workshop.	Researchers encourage explanations and takes notes.

3.2.3 Materials: Information Visualization Examples

The visualizations were collected from Instagram and X [Twitter] using the inbuilt search tool within the applications. The keywords used in the search included “climate”, “climate change”, “climate crisis” and “environmental issues” [in Turkish; *iklim, iklim değişimi, iklim krizi, çevresel sorunlar*]. To investigate the most current visualizations, the visualizations published between 2019-2023 were acquired. After excluding duplicates, 104 visualizations were left to be evaluated for this study. Please see Figure C.1 through Figure C.104 in Appendix C for visual materials[2].

The source of visualizations are as follows:

- News outlets: BBC Turkish, TRT *Haber* [Turkish Radio and Television], Anadolu Agency), *gzt*, *İklim Haber*,
- Non-governmental organizations (NGOs): TEMA *Vakfı* [Turkish Foundation for Combating Soil Erosion], Greenpeace Turkey, *Yuvam Dünya*, Istanbul Climate Save, change.org/iklim, 350 Türkiye, *Ben de Buradayım* [I am here too]),
- Data visualization and social research companies (Konda Research, *Doğru Veri* [Right Data], *Veri Kaynağı* [Data Source],
- Social media of commercial companies (Dohi Agriculture, *Gıda Danışmanım* [My Food Consultant]
- Governmental organization (*Meteoroloji Genel Müdürlüğü* [General Directorate of Meteorology]).

[2] All figures in Appendix C (Figure C.1 through Figure C.104) are in the public domain and are free from copyright restrictions. Please see Appendix C for references of the images.

3.2.4 Analysis

Since information visualization field is a relatively new and rapidly-growing field, it lacks a solid theory (this is explained in depth in the previous chapter). For this reason, starting from an interpretivist research philosophy, this research adopts an inductive research approach to conduct an exploratory study. The answers for the research questions were sought after through an in-depth literature survey (Chapter 5) and analysis of collected data via five workshops. In the analysis of the data collected in workshops, thematic analysis was employed (Braun & Clarke, 2006). Each workshop is considered as a single data unit as the concepts for information visualization measures are generated together while participants have discussed and built on each other's ideas (Morgan, 1997).

Braun and Clarke (2022) define thematic analysis as "a method for developing, analyzing and interpreting patterns across a qualitative dataset, which involves systematic processes of data coding to develop themes – themes are your ultimate analytic purpose" (p. 47). They have pinned down this method in their article published in 2006 –according to Google Scholar this article was cited 226,515 times up until 2025. In their book 2022, the authors have re-titled the method as "Reflexive Thematic Analysis", reflexivity meaning the researchers have to be aware of their stand point and subjective impacts and influences (Braun & Clarke, 2022, p. 48). This subjectivity is not problematic, as a matter fact, it is reviewed as valuable (p. 56). Although climate change is a global issue, the selection of visuals and participants were exclusive to Turkey. The discussions that took place were focused on the Turkish audience and the data analysis was conducted with a mindset that is aware of this local and subjective context.

The thematic analysis process follows these steps: 1- The researchers familiarize themselves with the collected data set, in this dissertation the transcriptions of the

workshops. 2- The researchers individually code the transcriptions and discuss their codes. In thematic analysis, line-by-line coding, which is used in grounded theory is not encouraged. Instead, only coding data relevant to the study topic is expected (Braun & Clarke, 2022, p. 98). 3- Researchers analyze the codes and create the initial themes. These themes are "expression of shared or similar ideas or meanings, across different contexts" (Braun & Clarke, 2022, p. 122). 4- The initial themes are re-evaluated to create the final themes.

In the light of these steps, the analysis process of this dissertation is as follows: All researcher notes and video/audio recordings were transcribed. The transcription process was carried out manually for Workshop 1 and with the Transkriptor App for Workshops 2, 3, 4 and 5. Each automatic transcription was checked for accuracy by the researcher. Since the data collection, transcription and transcription check was conducted by the same researcher, familiarization with the data set also took place.

For the first level of analysis, each workshop was coded individually. Attention was given to approach the first level analysis with an open mind, without being limited or directed by the literature driven measures. Semantic coding was preferred as the researcher stayed close to the language of participants.

In the second level, the similarities and differences between the groups are examined by weaving back and forth between the raw data and the first level codes of each workshop (Coffrey & Atkinson, 1996). In the second level, the literature driven measures were taken into account during the analysis. This enables comparing and contrasting the experts' views with literature, but extensive effort is also made to understand any subtle differences between expert's accounts and literature driven

measures. The views which were found to be parallel with literature driven measures were explicitly categorized in a separate table. Through this step, initial themes were achieved.

In the third level, initial themes were discussed with a second researcher, again by going back and forth between first level and second level codes, as well as between workshops. Discussions continued until a consensus was reached. The codes are illustrated in Appendix E (See Figure E.1 through Figure E.26) and initial themes will be discussed in Chapter 5.

In the fourth level, a framework was reached by finalizing the themes. The framework incorporates both literature measures and measures emerging from expert accounts in the workshops. The measures were analyzed in relation to the overarching issues of climate change as expressed in the workshops.

3.3 Third Stage: Survey with Experts and the Conceptual Framework

To understand the relationship of these measures, to see if there is a hierarchy or a heterarchy, and to discover how these measures relate to climate change communication goals, a survey was conducted with expert designers (n=28). A hierarchy refers to a system in which the parts of the system are ranked according to their status or importance. A heterarchy refers to a system in which the parts of the system are not ranked and no part dominates the others.

The United Nations' Climate Action plan focuses on how effective communication on climate change can be achieved. In order for the communication of climate change to have impact, it is necessary to educate stakeholders and encourage them to take action while addressing this global problem (United Nations, n.d.). They advocate three important steps; 1- Using reliable scientific information (to stop misinformation and to create trust), 2- Putting forward the problems but also pointing to the solutions

(avoiding climate fatigue) and 3- Mobilizing action (be inclusive and convey urgency). A joint program of United Nations, the UNDP (United Nations Development Programme) has published an article by Fernando Andrade (climate change technical specialist of UNDP) on the key points to focus for climate change communication. These points are 1- Be clear and simple in conveying your message, 2- Make it more human and tell stories from everyday life, 3- Add hope so that action is possible, 4- Messages should be co-created with the stakeholders (be inclusive) and 5- Use reliable sources (Andrade, n.d.). With regards to UN Climate Action and UNDP sources, there three common goals between the two sources and these can be summarized as:

Goal 1- Ensure Trust through Reliable Information

Goal 2- Connect with Stakeholders with Clear, Inclusive, and Solution-Oriented Communication

Goal 3- Mobilize Participation with Urgency and Hope

To further examine the relationship between the identified information visualization measures and the overarching goals of climate change communication, a survey study is conducted. This survey aims to validate the proposed conceptual framework by collecting expert opinions on:

- The degree to which each measure aligns with the identified goals (creating trust, stakeholder engagement, and mobilizing action).
- The potential hierarchical or interdependent relationships among the measures.

The findings from this survey provide empirical support for the conceptual framework and help refine it for broader applicability in climate communication.

3.3.1 Survey Structure and Design

The survey consisted of three main sections. First section focused on participant information. This section gathered demographic and professional background data to contextualize the responses. Questions included participants' primary field of expertise, years of experience, and whether they had previous experience working with climate change-related visualizations. These variables were used to understand the distribution of the sample and ensure representation across relevant disciplines such as graphic design, data visualization, climate communication, and environmental sciences. Second section focused on evaluation of measures across communication goals. In this section, participants were presented with a list of twelve information visualization measures. For each of the three communication goals, participants were asked to evaluate the relevance of every measure using a 5-point Likert scale, where 1 = Not Important and 5 = Very Important. This structure allowed for an ordinal measurement of perceived importance, facilitating statistical analysis of central tendencies (e.g., medians) and rank order across the measures.

Following each evaluation matrix, participants were prompted to select up to five measures they considered indispensable for achieving the corresponding communication goal. This forced-choice task encouraged prioritization and contributed to the identification of core measures. Additionally, each goal was accompanied by an open-ended question, allowing participants to suggest any missing or overlooked measures, or to provide justifications for their selections.

The third and final section consisted of reflective and diagnostic questions to support framework refinement. Participants were asked whether they believed any essential measures were missing from the current list, and to identify what they

considered the three most important measures overall for effective climate change visualization. These final responses served as to validate the consistency and salience of the most frequently endorsed measures across different sections of the survey (See Appendix D for survey questions and structure).

The survey was created using Google Forms and distributed electronically to experts. The participants included experts who had taken part in the earlier workshops, as well as additional expert designers and communicators who were invited via email. Incorporating participants from the previous workshops ensured continuity and coherence, allowing those already familiar with the framework development process to reflect critically on its refinement. Their contributions were valuable in assessing whether the final list of measures accurately represented the themes that had emerged during qualitative discussions.

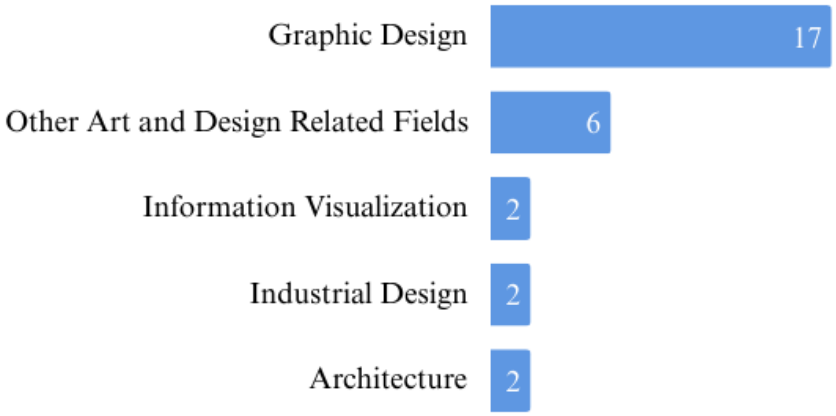
At the same time, inviting new experts brought fresh perspectives and minimized potential bias that might result from over-reliance on a single group. These new participants provided an external validation layer by evaluating the measures without prior exposure to the earlier discussions. This combination of in-depth familiarity and external objectivity enriched the dataset, enhanced the credibility and generalizability of the results, and supported a more balanced evaluation of the information visualization conceptual framework. In total, 28 responses (n = 28) were collected, meeting the minimum threshold required for ordinal data analysis and qualitative coding.

3.3.2 Participants of the Survey

The survey involved a total of 28 participants. The invitation to take part in the survey was sent out to all the participants of the workshops, preliminary study and additional invitations were sent out to other professionals in the design field. A total of

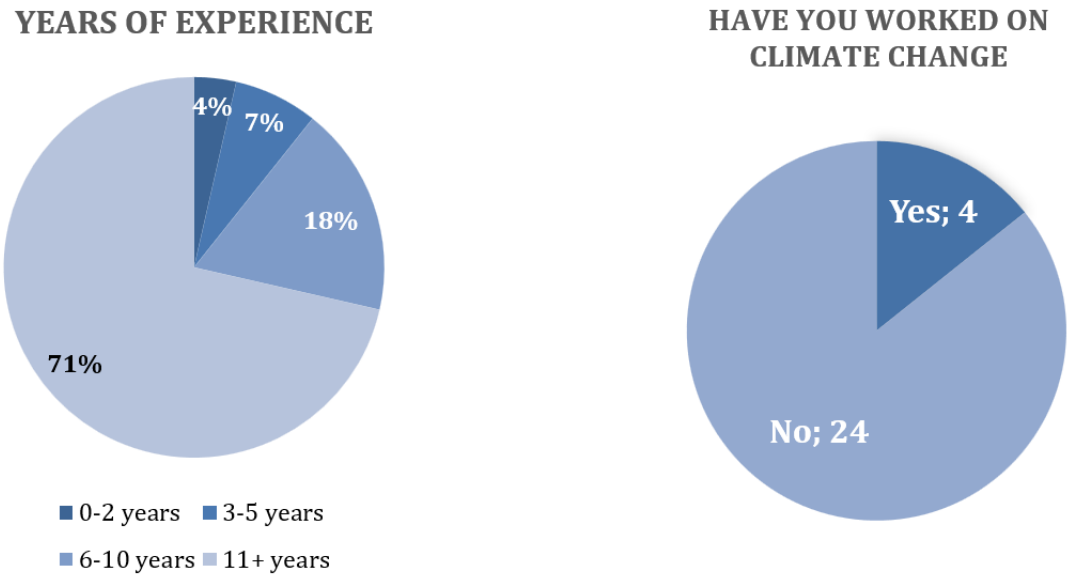
45 invitations were sent and 28 participants took part in the survey. Participants' areas of expertise predominantly included graphic design, with 17 out of 28 respondents identifying it as their primary field. Six participants indicated expertise in other art and design-related fields, suggesting a broader interdisciplinary design knowledge base within the participant group. Information visualization, industrial design, and architecture were each represented by two participants, demonstrating specialized knowledge in visual communication and spatial design disciplines (see Figure 3.1). This diversity of expertise, dominated by graphic design but complemented by related disciplines, contributed to a well-rounded perspective on visual design approaches relevant to climate change communication.

Figure 3.1 *Areas of Expertise of Survey Participants*



89% of the participants had more than 6 years of professional experience. Out of these, 71% had more than 11 years of experience. The participants were asked if they had worked on climate change before and 24 out of 28 participants indicated that they have not created visualizations on climate change (see Figure 3.2).

Figure 3.2 *Years of Experience and Climate Change Experience of Survey Participants*



3.3.3 Analysis of the Survey

The survey is designed to provide ordinal data, allowing for a structured interpretation of the rank order insights. This approach helps identify the relative importance of various information visualization measures, revealing which aspects are prioritized in climate change communication. By examining the rank order, we can determine which measures are perceived as most crucial by participants.

To assess central tendencies within the dataset, the median is used as a key statistical measure. The median provides a reliable indicator of the middle-ranked response, ensuring that the results reflect a balanced perspective rather than being skewed by extreme values. The survey included a Likert scale from 1 to 5, allowing participants to evaluate each measure on a graded scale of importance. The analysis is conducted with a sample size of 28 participants (n=28), ensuring a sufficient data set for meaningful interpretation. These findings contribute to the validation and refinement of the

Information Visualization Measures Conceptual Framework, helping to see if there is a hierarchy or to see the relationships between different visualization measures.

The quantitative data collected from the Likert-scale questions were analyzed using R, an open-source statistical computing environment. Specifically, the "likert" package was employed to process and visualize ordinal survey responses. This package is designed for analyzing and displaying data collected on Likert-type scales, making it particularly well-suited for the evaluation tasks in this study. The Likert visualizations generated in R provided a clear summary of response distributions across all twelve measures, grouped by communication goal. These visual outputs facilitated the identification of central tendencies, dispersion, and patterns of agreement or disagreement among participants. The visualizations not only helped to highlight the most and least selected measures for each goal, but also supported the interpretive process by offering an accessible representation of the data, aiding in both framework validation and reporting.

3.3.4 Towards a Conceptual Framework

In sciences and social sciences, there is no single definition or a set function of frameworks (Partelow, 2023). As a word, the Oxford English Dictionary defines framework as "a structure made of parts joined to form a frame; esp. one designed to enclose or support; a frame or skeleton" (*Framework*, n.d.). In social sciences there are two main types of frameworks: theoretical frameworks and conceptual frameworks. Concepts, together with their definitions, and pre-existing theories that are utilized for specific research are the components that make up a theoretical framework (*Theoretical Models and Frameworks: Overview*, n.d.). On the other hand, Jarvis (1999) and Tracy (2020) define conceptual frameworks as "visual illustrations" that show how concepts

within research are related to each other. This dissertation proposes a conceptual framework –with an empirically-driven structure– of information visualization measures for climate change visualizations, based on expert insights collected through interviews, workshops and a survey. Before going into details, it is necessary to explain that since the framework discussed in this dissertation is not a fundamental analysis of current theories that acts as a guide for researcher's assumptions, it is not a theoretical framework. It was explained in the introduction chapter of the dissertation that the field of information visualization is a relatively new interdisciplinary field and lacks an inclusive theory.

The framework is conceptual because it explains the key factors (measures) and their relationships. According to Miles and Huberman's (1994) definition: "A conceptual framework explains, either graphically or in a narrative form, the main things to be studied–the key factors, constructs or variables– and the presumed relationship among them" (p. 18). This conceptual framework has a data-driven structure, based on qualitative analysis rather than being solely derived from existing theories (Partelow, 2023, p.512). In developing empirically-driven frameworks, new variables may be introduced based on data-driven insights, while existing variables can be modified to enhance their accuracy and relevance. Moreover, clarifying relationships between variables strengthens the framework (p. 515). To sum up, this framework is a conceptual framework built on an empirically-driven structure. The framework structures and categorizes key measures while identifying their interrelations. Through thematic analysis, the study systematically organizes these measures into distinct categories, offering a structured approach to understanding the key characteristics of climate change visualizations. Furthermore, while the framework is informed by previous literature on information visualization and climate change communication, it goes beyond a

conceptual framework by validating its findings through expert engagement and iterative refinement.

By combining empirical and analytical elements, this framework provides a context-specific and practitioner-informed model for designing effective climate change visualizations. It can guide information visualization designers within the context of climate change communication. To further validate the framework, additional data was collected through an online survey sent out to designers working with information visualizations including the participants of the previous workshops.

4. MEASURES IN INFORMATION VISUALIZATION

This chapter presents a comprehensive review of the literature on the concept of "measures" in information visualization. The purpose of this chapter is to identify, categorize, and map out the range of measures that have been defined in previous studies, with the aim of constructing a foundation for the conceptual framework developed in this dissertation. Following the principles of a scoping review (Peters et al., 2020), the goal is not to evaluate the effectiveness of individual measures, but to map the range, diversity, and conceptual boundaries of what constitutes a "measure" in the context of information visualization.

Given the interdisciplinary nature of information visualization—spanning graphic design, cognitive science, human-computer interaction, communication studies, and increasingly, climate change communication—existing literature uses various terms to refer to what this study calls "measures," including *criteria*, *metrics*, *qualities*, or *cognitive dimensions,* often with different meanings depending on the context (Borgo et al., 2013; Munzner, 2014). While there is agreement that visualization effectiveness is shaped by a mix of cognitive, perceptual, and communicative factors, there is no consensus on a unified set of measures. Therefore, this chapter focuses on mapping the diversity of measures in order to create an informed basis for further empirical investigation.

In accordance with updated methodological guidance for scoping reviews (Peters et al., 2020), this literature review was guided by broad research questions and inclusion criteria to ensure a wide capture of relevant concepts. Rather than narrowing down to a single discipline or context, the review aimed to uncover recurring themes and approaches used to assess or define what makes an information visualization effective. Since scoping

reviews are “exploratory and descriptive in nature” and aid in sorting out complex and heterogenous literature (Peters et al., 2020), this methodology fits the aim of mapping out and exploring the conceptual landscape rather than testing hypotheses.

To identify relevant literature, an initial set of keywords including “measure”, “quality”, and “factors of information visualization” were used to search academic databases, beginning with ACM and IEEE as primary sources. As the initial search revealed new measures and concepts, the set of keywords was expanded accordingly, incorporating emerging terms such as “clarity”, “credibility”, “saliency”, “engagement”, and “aesthetics” among others. This iterative keyword expansion process ensured comprehensive coverage of the diverse range of measures present in the literature, facilitating a thorough exploration of how visualization effectiveness is conceptualized across different research contexts.

The chapter is organized into five main categories derived from the literature: (1) Perception and cognition-oriented measures, focusing on how viewers interpret visual encodings (e.g., Cleveland & McGill, 1985; Ware, 2012), (2) Task-oriented measures, related to the usability and functionality of visualizations for decision-making (e.g., Amar & Stasko, 2004), (3) Affect-oriented measures, addressing emotional engagement and aesthetic appeal (e.g., Bateman et al., 2010), (4) Goal-oriented measures, which consider communicative intentions such as actionability or memorability (e.g., Segel & Heer, 2010; Sheppard, 2005), and (5) Usability-based measures, drawn from interaction design and user experience research (e.g., Nielsen, 1994; Hearst, 2009). Each category reflects different theoretical and practical concerns, from visual clarity and speed to engagement and actionability. By organizing the measures this way, this chapter provides the

groundwork for the development of a climate-specific information visualization framework, discussed in the subsequent chapters.

Measure describes the qualities of an information visualization that characterize or clarify what constitutes an effective information visualization. There is no single definition for the term and various researcher have used other words such as *quality* (Quispel et al., 2016); *cognitive concept* (Borkin et al., 2016); *criteria* (Quispel et al., 2016); *factor* (Quispel and Maes, 2014; Szoltysik, 2016; Kim et al., 2017); *metrics* (Behrisch et al., 2018; Saket et al., 2016). In this dissertation the term *measure* is taken as similar to the term *aspect* or *dimension* –a particular feature or part of an entity.

With the aim to classify measures in information visualization Bolte and Bruckner (2020) come up with four categories: perceptual measures [e.g. Gestalt principles], task-oriented quality measures [e.g. visual clutter model by Bertini and Santucci (2011)], structure-oriented measures [e.g. data-ink ratio by Tufte (1990)], and meta-perceptual process measures [e.g. memorability, engagement and aesthetics]. Similar to Bolte and Bruckner's (2020) classification, in this study measures found in literature are grouped under five categories: perception and cognition oriented, task oriented, affect oriented, goal oriented and measures derived from usability (see Table 4.1 for groups and listed measures).

Table 4.1 *Various Measures Found in Literature*

Group	Measure	Selected References
Perception & cognition-oriented	comprehension	Friel et al. (2001), Bateman et al. (2010), Mayr and Schreder (2014), Ballantyne et al. (2016), Lee et al. (2017), Yoghourdjian et al. (2018), Obie et al. (2019), Chun (2020), Andry et al. (2021), Burns et al. (2022), Stokes et al. (2023)
	memorability	Bateman et al. (2010), Isola et al. (2011), Borgo et al. (2012), Lam et al. (2011), Li and Moacdieh (2014), Haroz et al. (2015), Borkin et al. (2016), Alper et al. (2017), Larache et al. (2018), Obie et al. (2019), Pena et al. (2020), Sezen et al. (2020), Coelho and Mueller (2020), Franconeri et al. (2021)
	clarity	Tufte (1990), Kostelnick (2008), Bishop et al. (2013), Garcia-Retamero and Cokely (2013), Ballantyne et al. (2016), Szoltysik (2016), Neset et al. (2016), McGurgan et al. (2021), Andry et al. (2021), Ajani et al. (2022)
	saliency	Herring et al. (2017), Matzen et al. (2018), Xiong et al. (2020b), Franconeri et al. (2021), Traver et al. (2021)
Task-oriented	accuracy	Zhu (2007), Kim et al. (2017), Dodge (2018), Saket et al. (2019), Xiong et al. (2020a), Waldner et al. (2020), Franconeri et al. (2021), Dy et al. (2021), Burns et al. (2022), Liu and Wu (2022)
	speed	Haroz and Whitney (2012), Gramazio et al. (2014), Haroz et al. (2015), Newell et al. (2016), Franconeri et al. (2021)
Affect-oriented	credibility	Tufte (1990), Johansson et al. (2010), Pandey et al. (2014), Sacha et al. (2016), Kennedy et al. (2016), Glaas et al. (2017), Kong et al. (2019), Hahn and Berkers (2020), Franconeri et al. (2021), Burns et al. (2022)
	engagement	Wolf and Moser (2011), Dörk and Collins (2013), Boy et al. (2015), Haroz et al. (2015), Kennedy et al. (2016), Kim et al. (2017), Christel et al. (2018), Bryne et al. (2020), Parsons et al. (2020), Romat et al. (2020), Andry et al. (2021), Schuster et al. (2023)
	aesthetics	Cawthon and Moere (2007), Inbar et al. (2007), Moere and Purchase (2011), Quispel and Maes (2013), Dick (2014), Shen (2018), Quispel et al. (2018), Parsons and Shukla (2020), Coelho and Mueller (2020), McGurgan et al. (2021)

Group	Measure	Selected References
	enjoyment	Bateman et al. (2010), Saket et al. (2015), Amini et al. (2018), Kim et al. (2019), Sezen et al. (2020), Romat et al. (2020), Sumedh et al. (2024)
Goal-oriented	actionability	Pandey et al. (2014), Huang et al. (2015), Glaas et al. (2017), Herring et al. (2017), Adams (2018), Ivankovic et al. (2021), De Caspell and Vasseur (2021), Sorapure (2023)
	personalization	Kang et al. (2017), Herring et al. (2017), Romat et al. (2020), Zhang et al. (2020), Terrado et al. (2022).
Usability	efficiency	Zhu (2007), Forsman et al. (2013), Parsons et al. (2020), Franconeri et al. (2021), Cavaller (2021)
	utility	Ellis and Dix (2006), Zhu (2007), Moero and Purchase (2011), Cavaller (2021)

4.1 Perception and Cognition-Oriented Measures

Perception and cognition-oriented measures are the ones extensively studied in literature. These measures often take their roots in perception and cognition theories in psychology and use quantitative and qualitative methods. Perception is about how human visual processing takes place, and cognition focuses on how the received visual cues are understood and restored in the brain. In other words, these measures are derived from a search for how humans see and make sense of what they see. Ware (2012) states that if we learn the mechanics of perception and cognition, we can then transfer this knowledge to creating effective information visualizations (p. xvi). Perception and cognition-based principles may aid in highlighting significant data patterns, lowering cognitive load for easier understanding and keeping clear of confusing or misleading visualizations. Four measures will be explained under this group: comprehension, memorability, clarity and saliency.

4.1.1 Comprehension

Comprehension and understanding are used interchangeably by various researchers and there are varying definitions on both. Friel et al. (2001) define comprehension as the capacity of graph readers to infer meaning from their own or other people's graphs; and different levels of comprehension are elicited by different levels of questioning (p. 132). Among other researchers Wolf and Moser (2011) define understanding as "acquiring and employing factually correct knowledge" on specific issues (p. 548). Similarly, Burns et al. (2022) claim that understanding is more than just extracting data points from a chart; viewers should be able to synthesize information, assess its correctness and be able to use that information later (p. 19). To put these definitions together, comprehension or understanding has different levels and it is about acquiring information, assessing it and then being able to utilize it for other purposes. Visualization literacy is also related to comprehension. According to Lee et al. (2017) "Visualization literacy is the ability and skill to read and interpret visually represented data in and to extract information from data visualizations" (p. 552). Visualization literacy studies also focus on sense-making which is similar to comprehension but has different definitions for different researchers. According to Börner et al. (2016) researchers generally take sense-making as "high-order thinking" i.e. synthesis and evaluation. However, there is also "lower-order thinking" which includes awareness and understanding (p 199). Burns et al. (2022), defines sense-making as the whole of data-based decision-making processes (p. 4515).

4.1.1.1 Levels of Comprehension

Although there are different definitions for comprehension, researchers propose very similar models on how comprehension takes place. Bertin (1973) states that there

are three levels in graph interpretation; elementary, intermediate, and comprehensive (as cited in Lee et al., 2017, p.552). At the elementary level, users simply extract the information. In the intermediate level, they start detecting patterns and trends and in the final level they are able to make comparisons in accordance with the data and their prior knowledge. Friel et al. (2001) also presents three levels for comprehension: elementary, intermediate and advanced level. The elementary level consists of extracting data from a chart. The intermediate level includes finding relationships in data and comparisons. The advanced level includes extrapolating, generating new knowledge and also predicting further scenarios (p. 130). In another study by Curcio (1987), similarly, users read graphs in three stages, they read the data, they read between the data and finally they read beyond data (p. 384). Burns et al. (2020) claim that understanding can be divided into three parts; analysis, synthesis and evaluation (p. 21). These studies collectively show that comprehension is a complicated process that takes place in stages.

From another point of view Shah and Freedman (2011) argue that there are two types of processes going on; bottom-up processes that involve visual characteristics of graphs and top-down processes that include prior knowledge of the user. In other studies, understanding is evaluated beyond the evaluation of mere perception. Burns et al. (2020) bring in Bloom's taxonomy to create a framework for evaluating understanding beyond perception (Burns et al., 2020, p.20). Specifically on visualizations, Friel et al. (2001) put forwards actions of comprehension: 1- Recognizing elements of a chart. 2- Ability to talk in specific terminology related to charts. 3- Grasping the relationship with data and the chart. 4- Responding to questions for interpreting data. 5- Selecting appropriate charts for certain tasks. 6- Being aware of the context of the chart (p.146) However, the majority of

the effort in comprehending a chart is spent on reading the information on axis and labels again and again (p. 139).

4.1.1.2 Factors Affecting Comprehension

Graph understanding is also influenced by a number of important elements, including the reader's qualities, task features, characteristics inherent to the visualization field, and the reasons for utilizing graphs (Friel et al., 2001, p. 132). Evaluating elements of visualizations such as shapes, colors, embellishments, annotations, and evaluating overall information density (simplification and lowering cognitive load) are among the studies conducted in the field.

Shapes, colors and embellishments: Andry et al. (2021) have found out that when two versions of visualizations were compared; embellished and minimally designed, there was no significant difference in understandability and clarity of these visualizations. As a conclusion to a conducted perception test, Giovannangeli et al. (2021) argue that in detecting outliers in visualizations, when both color and shape are used to encode data, user performance drops drastically. Mixing visual attributes such as color and shape can negatively impact outlier detection. Test participants explicitly preferred color over shape in showing different data and using more than 7 colors made visualization more difficult to understand (p.16). Mayr and Schreder (2014) have argued that isotypes ease comprehension for users with lower levels of literacy due to their intuitive nature. However, scientific evaluation behind these ideas is very scarce (p. 147).

Burns et al's (2022) findings imply that pictographs may be used by designers without compromising user comprehension in place of more conventional geometric forms. A second experiment by Burns et al. (2022) showed that some users found pictographs helpful in envisioning the topic and others found them cluttered and time

consuming in terms of comprehension (p 4516). Bateman (2010) came to the same conclusion.

Annotations: Charts that include visuals and text annotations are preferred by users. According to user comments, the annotations and visuals together aid the users in understanding. The clutter did not matter, the understanding was rated higher (Stokes et al., 2023, p. 1240). According to Stokes et al. (2023) textual annotations have a positive effect on comprehension and they also enable a more effective storytelling. Their findings from a user study conducted on text preference also aligned with this statement. Contrary to traditional beliefs in data visualization, observational annotations, whether through direct or indirect labeling, do not offer any added benefit for enhancing comprehension (Chun, 2020, p.93).

Information density: In their review that focuses on network diagram comprehension, Yoghourdjian et al. (2018) conclude that large and dense graph visualizations pose challenges to understanding and comprehension. The researchers emphasize that human capacity (cognitive scalability) should be taken into consideration to ensure effective use for network diagrams. The BBC Specials team emphasizes the importance of making their work accessible and appealing to all sections of society. They aim to avoid “patronizing simplicity” while ensuring that their graphics are understandable, especially since some audience members may feel intimidated by complex charts and graphs. They specifically say that charts remind them of mathematics class at school (Dick, 2014, p.502).

According to Zamith (2019) in data journalism, journalists often prefer simpler visualizations, perceiving semiotic simplicity as more effective and accessible. This preference for lower complexity may stem from a broader journalistic culture that values

simplification (p. 484). Majooni et al. (2017) explore how instructional design strategies, such as scaffolding theory and chunking, can enhance comprehension in infographic design by reducing cognitive load. The study presents two contexts in infographic form, divided into smaller chunks and displayed across four different layouts, all aligned with scaffolding principles. To assess the impact of layout on comprehension and cognitive load, participants answered conceptual questions about the infographics, and their gaze data (fixations, saccades, blink rate, and pupil dilation) was recorded and analyzed using a linear classification method. The results show that zig-zag layouts (left to right and top to bottom) better reduce cognitive workload and improve comprehension.

User characteristics: It is particularly essential to promote comprehension and understanding when the target audience has little understanding of the subject, graphing standards, numeracy abilities, or recall capacity (Franconeri et al., 2021, p. 150). With agreement to this statement Schuster et al. (2023) suggest that the sense-making process is extremely personal and impacted by an individual's prior experiences, beliefs, and viewpoints.

4.1.2 Memorability

Memorability and recall are among the most studied measures together with comprehension. Recall and memorability are aspects also studied under visualization literacy research. These aspects aid visualizations in becoming more popular and accessible for the general public (Alper et al., 2017, p. 5486). Putting together a taxonomy of evaluation methods for information visualizations, Lam et al. (2011) have underlined memorability as a new metric for that time and gave examples on how researchers began exploring it (p. 1529).

Stemming from perception studies, memorability also has different types. According to Lonsdale and Lonsdale (2019) processing visual information involves three types of memory: iconic memory, working memory and finally the long-term memory (p. 15). Iconic memory is the first stage, when a user sees the visualization, it occurs instantly and a well-structured contrast has a lot of effect on this type of memory (Lonsdale & Lonsdale, 2019, p. 15). Haroz et al.'s (2015) study utilized iconic memory and working memory which will be explained shortly. Following iconic memory, working memory starts. At this stage the information received is divided into chunks and if there is a lot of information, chunks can overload and cause working memory to struggle (Lonsdale & Lonsdale, 2019, p.15). The chunks of information are also related to scaffolding theory of teaching, where you present information as chunks and build upon knowledge with chunks over chunks. This is related to Majooni et al.'s (2017) study in which they have tested various layouts for introducing these charts to enable better comprehension. Lastly, the chunks of information are moved to long-term memory, this is the part where effective visualizations can pass the prior stages and reach the long-term storage (Lonsdale & Lonsdale, 2019, p.15). To reduce to cognitive load and aid memory processes, Lonsdale and Lonsdale (2019) underlines the importance of information chunking, use of visual cues, using familiar design elements and charts, discarding use-free visuals and content, creating order, hierarchy, consistency and emphasis among visuals and verbal elements (p. 16).

In an early study, in search of what makes an image memorable, Isola et al. (2011) have conducted online tests and found out that memorability of an image is consistent for different viewers. Color choice (red specifically) and human figures and objects at a human scale enhance memorability, whereas natural landscapes and expansive views are

generally less memorable (p. 150). Similarly, Larache et al. (2018) investigate the memorability of data visualizations with an aim to establish a predictive model for visualization memorability. They conclude that both visual elements and attention-related factors play a significant role in determining the memorability of visualizations.

4.1.2.1 Images and Memorability

According to Borkin et al. (2013), visualizations that contain pictograms (any type of cartoons or images that are recognized by humans) are more memorable compared to other visualizations that lack pictograms. In a later study, Haroz et al. (2015) have conducted experiments with pictographs to understand their effect on extracting information from charts. As a result of their tightly controlled experiments, they conclude that pictographs enhance memory but when they are used as "superfluous images" (decorative background images), they both decrease memorability and the speed of information extraction (p. 1198). They simply become distractions. The researchers also claim that stacking pictographs improves memory recall compared to stretching them, especially for small quantities. Furthermore, pictographs may aid memory when working memory is under load, helping to keep information distinct (p. 1199). Later on Wang et al. (2018) came to the same conclusion that in infographic design, pictographs are frequently used to help people understand and recall information quickly. Adding to that viewers, specifically lay viewers show better results of memory for visualizations with anthropomorphic icons (Cairo & Klein, 2018). Laptev and Orlov (2016, p.53) argue that pictorial charts featuring a pictogram, a stylized drawing, or a photographic image are more memorable than those using simple geometric shapes (such as rectangles), which resemble basic bar charts. Although users take more time to process charts with pictograms, the style of the pictogram, whether photorealistic or more abstract, does not

affect the overall speed (p.54). This finding is in line with Borkin et al. (2016) conclusion that pictograms have no negative effects on the recalled message of the visualization (this is evidence against the chart junk debate) (p. 526).

In a more recent study Pena et al. (2020) have found that relevant design enhancements improved recall of visualization titles and thematic elements but had little impact on remembering specific data values. Their findings indicate that enhancements can boost the memorability of certain chart aspects, provided the design aligns well with the information. However, the researchers claim that unrelated embellishments lead to poorer recall of chart topics compared to non-enhanced charts. Irrelevant design modifications or embellishments can distract viewers and decrease memorability when the users cannot establish a clear connection with the embellishment and the informational content. Although the findings of Pena et al. (2020) align well with other findings in literature, their imagery does not follow design principles. The color choices, the textures and overall design decisions have a lot of room to be improved from the design perspective.

4.1.2.2 Other Factors that Affect Memorability

In their study Kong et al. (2019) have found that the title of a visualization increases the memorability. In a further study, Borkin et al. (2016) have studied long-term memorability of visualizations and which part of the visualization is more memorable. Their findings indicate that title is the most important textual element for memorability (p. 525). Titles are very significant in recalling the message of the visualization. Opposed to memorable titles, Chun (2020) has observed that direct labeling does not improve information recall, despite the reduced cognitive load associated with

not having to decode keys. The researcher states that these findings challenge established best practices advocated by theorists, data journalists, and existing literature (p. 94).

Following textual elements, color was among the evaluated elements of design for memorability. Visual focus in info vis such as highlighting with color has a positive impact on the user's memorability of the highlighted part of the data (Ajani et al., 2022, p. 3351). The researchers test focus (with color) together with declutter. First, they declutter the visualization and then add a color focus. On the contrary to declutter principle, Borkin et al. (2013) have found out that visualizations that have 7 or more colors are more memorable compared to visualizations with less color.

A third element studied for effective memorability was the use of narratives. Comparing interactive visualizations without author narratives versus presentation films with author-driven narratives, Obie et al. (2019) have discovered that the latter greatly improved short-term fact memory. Nonetheless, there is no apparent distinction between the two forms in terms of long-term memory of facts (p. 119). However, in terms of comprehension, Obie et al. (2019) state that visualizations supported with a narrative turned out to aid the comprehension process (p. 119). Researchers who support narrative use also comment on embellishments. Advocates of communicative and storytelling information visualization have embraced the ability of figurative images to boost memorability and engagement. They acknowledge that visualizations are frequently created with communication as the main goal, rather than being used purely for analytical purposes (Bryne et al., 2019, p. 46).

Layout is also among the studied design elements. Marriot et al. (2012) have conducted an experiment on the effect of layout on memorability of network diagrams. They have asked their participants to look at small network diagrams and to draw them

from memory. At the end of their experiment, the results indicate that features such as "symmetry, collinearity, and orthogonality" greatly enhanced recall and are consistently reflected in participants' drawings, whereas node alignment and parallel edges have a lesser effect (p. 2484).

Finally, data density and chart familiarity are assessed by researchers in terms of memorability. Borkin et al. (2013) argue that visualizations with higher visual densities are more memorable than low density (minimally designed) visualizations. So, more chart junk and more clutter make a visualization more memorable but let's not forget that the researchers point out that they only tested for memorability and engagement or comprehension. Overall, cluttered visualization might work for memorability, but they may not work for better comprehension or faster comprehension.

4.1.3 Clarity

Clarity in information visualization is a measure to ensure the message and the data are presented in a straightforward manner. The common aim is to lower cognitive load and avoid any confusion. As Szoltysik (2016) observed, clarity is a key factor in creating readable and simple infographics that enable easy interpretations for users. In an earlier study, Kostelnick (2008) has explained clarity in data visualization design as not a simple concept but a complex and sometimes ambiguous one. It is shaped by various factors, including perception rules, cognitive models, aesthetics, learning and experience, the rhetorical context, and emotional appeals that capture reader interest. As data displays transition from print to digital formats, clarity evolves further, as readers gain control over how data is visualized. Interactivity also plays a significant role by enabling readers to explore complex datasets without processing all the information in a single view (p. 128).

Despite its complicated nature, clarity should not be confused with oversimplification. Tufte (1990, p. 34) argues that clarity and simplicity are not the same as being simplistic or underestimating the audience. Tufte emphasizes that designers have a "moral" responsibility to treat their audience with respect, acknowledging their intelligence and addressing them thoughtfully and attentively. Bishop et al. (2013) confirms Tufte and warns against over-simplifying or dumbing-down information. What should be in focus is to have a "rich texture of data", a relatable context, a design based on data-ink ratio[3] to present all this information (Tufte, 1990, p.51). What is opposed to clarity is clutter and confusion. The aim has to be about finding appropriate design solutions to present the data, not to decrease data complexity or blaming the user for lack of ability (p. 53).

In relation to Tufte's statements, McGurgan et al. (2021) have conducted interviews with graphic designers to examine data-ink ratio and the design process. It was observed that clarity, which is described as readability or "ease of use", and minimizing clutter were mentioned by almost all interviewees as design goals. Participants in the interview desired their charts to be easily comprehensible to others (p. 191). From the user perspective, when Andry et al. (2021) have compared two versions of the same visualization, embellished and minimally designed, they have observed no significant difference in understandability and clarity of these visualizations. As a matter of fact, adding a visual focus to the visualizations results in higher ratings for clarity and aesthetics in information visualizations by users (Ajani et al., 2022, p. 3351). Against

[3] In his 1983 book *The Visual Display of Quantitative Information*, Edward Tufte introduced the concept of the data-ink ratio, defining it as the proportion of ink used to convey actual data relative to the total ink needed to print a graphic. Essentially, the data-ink ratio measures how much of a visual's elements directly communicate information compared to all the elements present.

Tufte's warnings, Newell et al. (2016) state that visualization formats differ in clarity and readability for diverse target audiences. Clarity relates to aesthetics and entails the choice between employing intricate design elements or simple abstract forms. Visualizations that include real-world elements [like pictograms or imagery] can effectively engage diverse audiences. Abstraction [forms like lines, shapes, or minimalist charts] facilitates the recognition of trends through spatial reasoning and pattern identification. A visualization developer must assess if the integration of complex designs and features enhances or diminishes clarity (p. 4-5).

To uncover factors that affect clarity, various researchers have evaluated visualization design from different perspectives. According to Ballantyne et al. (2016) visualizations and imagery have a clarifying effect on the issue of climate change for lay audiences. Through the data they have collected over a focus group study with high school students, the researchers have come to the conclusion that visualizations were highly associated with clarity about the issue. They also claim that with clarity, climate change became less abstract and more concrete for the viewers (p. 81). In another study on climate change visualizations, researchers have developed a tool to provide information to users. VisAdapt is a visualization tool designed to provide local and personal climate risk information to Nordic home owners. The aim is to let the end users navigate through the tool and understand the possible risks they might face for their own specific location. The developers of the tool have evaluated the tool through user studies and found out that the tool made climate information "accessible and concrete" for users (Neset et al., 2016, p. 71). By rendering climate risks "accessible", VisAdapt enables users to effortlessly search and locate relevant data for their unique locations. The "concreteness" of the information increases clarity by delivering information in a practical and relevant style,

aiding consumers in understanding complex climate-related risks. In another study by Garcia-Retamero and Cokely (2013), visualizations are found to vary in effectiveness and are most useful when they are transparent. What they mean by transparency is that the visualizations are clear and straightforward, with well-defined elements that accurately represent the information, especially by making part-to-whole relationships in the data (p. 392).

To sum up, clarity is a complex measure as stated by Kostelnick (2008). Factors that affect clarity in information visualization include perception, cognition, aesthetics, user experience, context, emotion, interactivity, readability, simplicity, engagement, transparency, concreteness, focus, abstraction, relatability, and accessibility.

4.1.4 Saliency

Xiong et al. (2020b) define saliency as “the most noticeable and important feature” in a visualization (p. 3052). Traver et al. (2021) define salience as the "ability of an object, or part of a scene to attract our visual attention (p. 1). Under this definition there are two subgroups: spatial salience and temporal salience. Spatial salience shows where the attention is focused, whereas temporal salience shows when attention happens and how it changes over time.

Xiong et al. (2020b) point out that a viewer’s prior knowledge and annotations influence which features in a visualization stand out. Miscommunication can occur when experts presume that others recognize the same features as salient. Xiong et al. (2020b) propose several strategies to deal with this miscommunication caused by assumptions about saliency in visualizations. These include redesigning or reformatting visualizations to view data from new perspectives, seeking feedback to identify misinterpretations and improve clarity, and depending more on the wisdom of the crowd by gathering insights

from multiple viewers to gain a more comprehensive understanding of data patterns (p. 3061). However, these suggestions are not scientifically proven and require empirical testing to confirm their effectiveness.

Herring et al.'s (2017) study proposed that exploring geographically close areas would heighten the salience of climate change and influence user beliefs and attitudes more significantly; however, their findings did not reveal a notable effect in this respect. So, a direct relationship between saliency and localization was not proved.

Matzen et al. (2018) created the Data Visualization Saliency (DVS) model to solve saliency model deficiencies. They used eye-tracking data from human volunteers to compare the DVS model's saliency maps to those of other models to assess its efficacy. In another study, it was pointed out that to guide the viewers' eyes to the critical comparison, designers highlight the most important part of a visualization, usually with color. They also add text (annotations) (Franconeri et al, 2021, p.125-126). However, the researchers also claim "These techniques are less important for experts, who rely on prior experience to guide their attention" (p. 125).

4.2 Task-Oriented Measures

Accuracy and speed are the prominent task-oriented measures for achieving effectiveness in information visualizations. Task orientation is about understanding how users complete given tasks such as data extraction, comparison, and decision-making. While accuracy refers to the correctness of the task outcomes, speed focuses on how quickly users can complete these tasks. There are several factors that affect these measures including chart types, visual embellishments, user familiarity, data complexity and structure.

4.2.1 Accuracy

Accuracy is a measure that is related to accurate results of user tasks. Dictionary definition for accurate is “free from error, exact” (*Accurate Definition & Meaning - Merriam-Webster*, n.d.). For information visualizations, Saket et al. (2019) use the term “accuracy” to describe how accurately users can accomplish tasks using various kinds of visualizations. In literature, researchers have studied accuracy in relation to comprehension, data complexity, comparison of different chart types, embellishments, labels and user preference.

Liu and Wu (2022) take accuracy as the accuracy of reading and therefore relate it to comprehension. They have found out that people with higher verbal working memory performed better in reading comprehension. And there was no difference between participants studying in science majors or other majors. So, task accuracy depends on users’ level of comprehension.

In another study, Dy et al. (2021) state that accuracy decreases as data complexity increases. In an experiment they have conducted on users completing a decision-making task, they have found out that that chart type or familiarity of the user with chart type does not make a significant difference in accuracy (p. 10). In another study that included complex data, Christel et al. (2018) explain that visually representing probabilistic information often requires balancing scientific accuracy, functionality, and aesthetics, necessitating a transdisciplinary approach that involves scientists, users, and designers. According to their experience, interdisciplinary teams are most effective when given well-defined contexts for collaboration and sufficient time to foster mutual understanding (p.120). Consequently, accuracy is an essential measure as data becomes more challenging to manage.

Previously, Yuan et al. (2019) have examined how visual features impact accuracy in interpreting averages. They find that spatial position encoding works well for single-value comparisons, while summed area can serve as a proxy for averages in more complex, multi-value comparisons. The study also reveals that accuracy declines as comparison complexity increases, such as moving from 1vs1 to 6vs6 comparisons (p. 672). Graph type influences accuracy as well, with dot plots often outperforming bar graphs for group comparisons due to their reliance on spatial positioning. The research suggests design adjustments, like using bar graph outlines to reduce area salience, can enhance focus on critical features and improve accuracy (p. 674). Nevertheless, not only data complexity but also chart type affects accuracy. A further study by Waldner et al. (2020) also states that task accuracy of users is found to be higher for linear charts compared to radial charts. This is also true for chart efficiency; users completed tasks more correctly and fast with linear charts. Discussing yet another chart type, Dodge (2018) evaluates the effectiveness of maps in the context of news media and communication. The researcher suggests that well-designed cartography can positively impact how issues are communicated to audiences, potentially enhancing accuracy and clarity in journalism. However, the author also points out that maps can be manipulated to distort or mislead when not properly created (p. 949). In a more recent study, departing from the observation –individuals often underestimating the average positions of lines in graphs while overestimating the average positions of bars– through three empirical studies, Xiong et al. (2020a) have found that systematic bias for position estimation remain consistent regardless of whether the data was varied or kept consistent without variations (p. 304-305). In short, dot plots perform better compared to bar charts, linear charts prove better scores compared to radial charts, maps increase accuracy when

appropriately constructed and users have an estimation problem with both linear and bar charts.

For assessing the relationship between accuracy and embellishments, on one hand, Burns et al. (2022) claim that accuracy of user information extraction is not affected by pictorial embellishments. Their claim is on the contrary to data-ink ratio/embellishment discussion. On the other hand, Kim et al. (2017) approach embellishments with caution as they claim embellishments increase engagement and memorability but incorporating illustrations or images while accurately presenting data is a challenge. To solve this problem, they have designed Data-Driven Guidelines to help designers create accurate illustrations that align perfectly with data. Their tool specifically aids scaling custom drawn shapes to accurately show data. Testing another visual element, the use of labels, Franconeri et al. (2021) have observed that use of labels increased accuracy.

From another point of view, Saket et al.'s (2019) study have found a correlation between accuracy and user preference, indicating that consumers like visuals that improve the accuracy of tasks that need to be completed (p. 2505). In other words, users prefer charts that help them find out the exact information that they are looking for.

4.2.2 Speed

In literature speed is evaluated as the speed of completion of a task by the users. Often the researchers conduct controlled experiments in the lab, and they focus on a very small part of the visualization. The method of using controlled experiments is difficult since visualizations are made up of various elements including texts, visuals, colors, layouts… etc. These elements all work together to convey data and a desired message. When the elements are separated and tested as isolated elements the outcomes of the research become harder to apply to real life examples and cases.

Haroz et al. (2015) have conducted one of the most referred studies. Testing the effects of using pictographs in charts, Haroz et al. (205) have found out that pictographs did not significantly increase speed of information extraction compared to bar charts. However, when the pictographs were used out of context and as background images, they were distracting and they prolonged the information extracting thus decreasing speed (Haroz et al., 2015, p.1198). Haroz et al. (2015) do not provide a specific definition of "speed". However, they discuss speed in the context of information recovery from charts and how pictographs may impact the speed of understanding visual data. Another study that focuses on pictograms was conducted by Laptev and Orlov (2016). They argue that pictorial charts include three parts, visualization function, illustrations and semantic meanings inherent to pictograms (p.45). Pictorial charts may also make use of photographs, geometric shapes, silhouettes, hand-drawn sketches. In their study, using eye-tracking technology, Laptev and Orlov (2016) compare the use of different pictorial elements (photographs, figures, pictographic images and abstract geometric shapes) in data visualization in terms of their role in achieving effective visualizations. In terms of speed of problem solving, the researchers found no remarkable difference between different styles of pictographic elements.

In a previous study, Gramazio et al. (2014) have conducted research on speed of user searching tasks based on colors and space used in charts. The researchers found that search performance improves when colors are spatially grouped rather than arranged randomly. They observed that the number of marks has minimal impact on search speed in grouped displays but significantly slows reaction times in random displays. Additionally, response times are slowest for the smallest mark sizes, improving as mark size increases until they reach a plateau. Similarly, Haroz and Whitney (2012) highlight

that human attention to visual features like color and motion is limited, and exceeding these constraints reduces both response accuracy and speed. As a result of their experiment the researchers have found out that layouts that use grouping and color provided an increase in speed (Haroz & Whitney, 2012).

In a recent study Franconeri et al. (2021) state that accuracy and speed increases when direct labeling is used (p. 130). Adding to that statement, they also claim that there is mixed evidence on how clutter affects speed. Some axis marks and extra ticks increase speed although they clutter the design. In other research, (Ajani 2021), decluttered visualizations were found to increase speed (Franconeri et al., 2021, p131). Besides clutter, Newell et al.'s (2016) study that compared an interactive and a static information visualization on climate change shows that a static visualization is favored for its ability to provide all information at once (p.17). Interactive visualizations are usually preferred for increased user engagement but seeing all the data at once increases the task speed.

Overall, studies focusing on speed showed that use of pictographs do not positively affect speed (Haroz et al., 2015; Laptev & Orlov, 2016) and they are even distracting when used out of context (Haroz et al., 2015). Use of color and grouping elements in a design increases speed (Gramazio et al., 2014) but if there are too many colors then they may slow down task speed (Haroz & Whitney, 2012). Adding direct labels to designs increases speed but decluttered visualizations also work for faster speed (Franconeri et al., 2021). Interactive visualizations are engaging but still visualizations improve task speed (Newell et al., 2016). Still, it is not easy to apply these findings to design since speed measure is never isolated, it works together with other measures.

4.3 Affect-Oriented Measures

Affect oriented measures include credibility, engagement, aesthetics and enjoyment. These measures create different emotional effects on the user.

4.3.1 Credibility

Credibility is almost always discussed with the notion of trust. Mayr et al. (2019) describe trust as "...the user's implicit or explicit tendency to rely on a visualization and to build on the information displayed" (p. 1). Trust can be approached as the trust of the user or the trustworthiness of the data or its source. For example, Mayr et al. (2019) identify two main components of trust: trustworthiness (the qualities of the visualization) and trust perception (the user's subjective evaluation of the information). Factors influencing trustworthiness include accuracy, currency, completeness, objectivity, validity and predictability of the information presented. User-side factors affecting trust perception include prior knowledge, emotional responses, and the perceived relevance of the information. Similarly, to evaluate perceived credibility of a visualization, Kong et al. (2019) use metrics that have been used in other research on online media credibility. They take into consideration 5 components that make up credibility, these are accuracy, fairness, trustworthiness, bias, and completeness" (Kong et al., 2019, p. 6). In another study, Sacha et al. (2016) state that building trust is influenced by a number of elements, such as technical proficiency, visualization literacy, and the user's system knowledge and experience (p. 243).

Trust has a lot of factors that affect it but it can also be achieved through ethical practices. Floridi and Taddeo (2016) examine trust within the framework of data ethics, emphasizing its role in building public confidence in data practices. They underline the importance of trust and transparency in addressing the limited public understanding of

the benefits, opportunities, risks, and challenges of data science. While transparency is frequently suggested as a means to enhance trust, the authors also question what information should be disclosed and who the intended recipients of such transparency should be.

4.3.1.1 Trust in Data and Source

Kennedy et al. (2016) point out that trust in visualizations is impacted by their source or media location and users are skeptical when they are unsure about the media source (p. 10). In alignment, Mary et al. (2019) highlight that the credibility of the source is a very important factor in determining whether information is trustworthy. In a further study, some focus group participants expressed varying levels of trust in visualizations based on their source, indicating that seeing the logo of University of Oxford promoted a feeling of trust for them (Kennedy and Hill, 2018, p.839). Overall, this emotion of trust also had a positive effect on the overall engagement of the participants.

In the case of climate change, Hahn and Berkers (2020) state in their literature review that trust in both the source and message is very important for effective climate change communication. Trust strongly influences people's willingness to support and participate in actions against climate change. The researchers also underline that trust is essential for engaging with information visualizations. They also claim that visualizations are more likely to be perceived as credible if they appear realistic and are presented by trusted communicators, such as NGOs. Moreover, Glaas et al. (2017) claim that if climate change visualizations are credible and legitimate as they are also salient, they can induce trust and later action (p. 2). Therefore, the researchers connect trust with engagement, credibility and taking action.

Besides the source of the data, uncertainties in data also affect trust and credibility. The term uncertainty includes all future projections of data, e.g. how the carbon emissions in the future would affect global temperature rise according to different scenarios. Johansson et al. (2010) highlight that trust issues regarding data in International Panel for Climate Change (IPCC) reports have amplified the demand for clear and accurate communication of uncertainties, as well as the regional and global impacts of climate change (p. 156). Accordingly, users' level of trust increases by being aware of uncertainty as they make fewer mistakes when they are aware of these uncertainties (Sacha et al., 2016, p. 244). Being on the same page, Franconeri et al. (2021, p. 139) emphasize that effectively communicating uncertainty is essential for public scientific literacy because understanding uncertainty enables individuals to accurately assess the reliability of patterns or claims.

On data content, Tufte (1990) states, "data-thin" forgetful presentations both weaken the credibility of the source and encourage ignorance and apathy on the part of the audience. These designs undermine the audience's abilities of perception and make the data look suspicious, thus untrustworthy (p.50).

4.3.1.2 Trust and Design Elements

Tufte not only talks about data content but also talks about the visual elements that have an effect on trustworthiness. Tufte (1990, p. 34) argues that credibility is lost when charts are overloaded with unnecessary visual elements (embellishments), and he compares such designs to the appearance of a video game and poses the question "who would trust a chart that looks like a video game?" (p. 34). In relation to Tufte's claims, on the one hand, Burns et al. (2022) report finding mixed results on user trust and embellishments. Burns et al. (2022) state that for some users' charts with pictograms have

been cluttered, complicated and they have been perceived as less serious. For others, pictograms have enabled the topic to be more relatable (p. 4527). On the other hand, Nigel Holmes, who is the graphic designer of the visualizations that "looked like a video game", criticizes Tufte as "being trapped in the world of academia" and claims that engagement is more important for the market (Akbaba et al, 2021, p. 2).

Embellishments may also include photographs. O'Neil and Smith (2014) claim that photographs in particular are frequently seen as accurate depictions of reality, which makes them appear genuine rather than constructed. As an example, they point to the controversy over a Photoshop-altered polar bear image that was published in the journal Science alongside a letter on scientific integrity serves as an example of how this perception may lead to problems. An outrage was caused when the manipulated image was presented alongside a debate on scientific integrity (p. 74). This debate also affected trust in a profound way.

Another element of visualizations that affect trust is text, more specifically the title. They found out that when the title of a visualization is in contradiction with the data shown, the credibility of the information slightly decreased. The title was the part of the visualization that had the most impact on trust (Kong et al., 2019, p.345-346). Other studies on credibility include discussions on geo-spatial literacy and choropleth maps in terms of trustworthiness by Juergens (2020); persuasion and trust in public policy communication (Nyhan and Reifler, 2019); data driven visualizations and stories providing journalistic credibility in sports journalism (Horky & Pelka, 2017, p. 592) and discussion on user emotions: Users with negative feelings toward an issue tend to have lower trust towards visualizations and they question the source of the data more (Pandey et al., 2014, p. 8).

To sum up, trust in information visualizations is a complex term that depends on a number of factors, including the data source, design elements, and how well uncertainty is communicated. Credibility and trust can also be achieved through following ethical principles and maintaining transparency, which will ultimately enhance user engagement and the visualizations' overall impact.

4.3.2 Engagement

Engagement measure is among the well-studied measures in literature and is quite complex. There are numerous studies on it but still there is little agreement on how to achieve engagement. To understand its complex nature, a description of engagement may be a point of start.

4.3.2.1 Defining Engagement

In literature, the term engagement does not have a definition accepted by all (Mahyar et al., 2016; Hung and Parsons, 2017, p. 1709; McKenna et al., 2017, p.378). Defining engagement becomes significant when there is a need to increase engagement of the audience. This definition should be inclusive of measurable properties.

Engagement is frequently described by researchers through borrowing concepts from other disciplines (Hung & Parsons, 2017, p. 1709). It is described as an important factor in determining “the effectiveness and impact of a narrative visualization” (Mahyar et al., 2015; also cited by Amini et al., 2018; Zhi et al., 2019, p.677). From a behavioral point of view, engagement is defined by other researchers as the user’s will for investing time and effort in exploration and acquiring more knowledge from information visualizations (Boy et al., 2015) or captured attention of the user towards analyzing a visualization more closely (Haroz et al., 2015). Similarly, Wolf and Moser (2011) define

engagement as “a state of personal connection that encompasses cognitive, affective and/or behavioral dimensions” (p. 562). Kennedy et al. (2016) has defined engagement as the “processes of looking, reading, interpreting, and thinking” that occur when individuals view data visualizations in an attempt to make sense of them. This definition puts the user in an active position where they interact with visual data, including both cognitive and emotional responses of the users during the engagement process. Other researchers find these definitions as non-inclusive of the heterogeneous structure of engagement which is composed of different parts or levels (Mahyar et al., 2015).

Engagement is not a unified concept. Generally, the researchers dissect engagement into its parts to analyze this abstract concept and to turn it into a measurable notion. According to Mahyar et al. (2016) engagement has 5 deeper levels. For Amini et al. (2018) engagement has 5 attributes. Hung and Parsons (2017) describe it as an abstract, complex construct that has multiple parts. Kennedy et al. (2016) list 6 factors that influence engagement. The dissection of engagement by the above researchers are presented at Table 4.2.

Table 4.2 *Engagement Described by Mahyar et al. (2016), Amini et al., (2018), Hung and Parsons (2017) and Kennedy et al. (2016)*

5 Levels of Engagement (Mahyar et al., 2016) *Similar to Bloom's Taxonomy*	**5 Attributes of Engagement** (Amini et al., 2018)	**Multiple parts of engagement** (Hung & Parsons, 2017)	**6 Factors that influence Engagement** (Kennedy et al., 2016)
Expose (Viewing)	Focused attention	Psychology → flow, positive psychology, fulfillment, motivation	Subject matter
Involve (Interacting)	Enjoyment	Education → motivation, achievement, interpersonal relations	Source Media / Location
Analyze (Finding Trends)	Aesthetics	Gaming → game involvement	Confidence and skills
Synthesize (Testing Hypotheses)	Affective involvement	HCI → flow/fluid interaction, satisfying and pleasurable emotions, emotional, cognitive, behavioral	Emotions
Decide (Deriving Decisions)	Cognitive involvement		Beliefs and opinions
			Time

4.3.2.2 Importance of Engagement

Engagement is more discussed in research where the audience is not particularly expert in some aspects of the information visualization. They may be lacking domain knowledge or they may lack information visualization literacy. According to Boy et al. (2015) accessibility and engagement of data becomes important when the aim is to empower the public with insight and knowledge they will acquire from the data or information visualized. Mahyar et al. (2015) also underlines the importance of user engagement in cases where the users are not experts in neither visualization nor the domain.

4.3.2.3 Evaluating and Measuring Engagement

Since engagement is a complex measure, researchers tackle the problem of testing and evaluating engagement via various methods. Amini et al. (2018) have come up with a scale-based easy to use questionnaire covering five factors of engagement, and they have conducted the scale on 120 people. Other researchers have used existing evaluation questions on engagement by O'Brien and McKenna (Zhi et al., 2019). Some conducted experiments together with qualitative interviews (Coelho and Mueller, 2020; Franzoni et al., 2020; Walny et al., 2018; Saket et al., 2016). Qualitative role playing (Aseniero et al., 2020), interviews with open coding (Nowak et al., 2019) and perceptual experiments (Promann, 2018) are among the other methods used by researchers in evaluating engagement in information visualization.

According to Mahyar et al. (2015), constituting a framework that shows different levels of engagement is the first step in evaluating or measuring engagement. And these levels require separate evaluations, but these are left for further studies by the researchers.

4.3.2.4 Various Factors Studied for Assessing Engagement

Narrative elements or storytelling is among the factors studied by researchers. In search of the effects of narrative components on overall engagement in information visualizations, Boy et al. (2015) have conducted an experiment but they cannot firmly conclude that narrative parts of an interactive web-based visualization positively affect user engagement (p. 1457). They propose that emotional response and aesthetic experience can be analyzed to get a better understanding of how engagement is affected. They find measuring engagement, especially for online mass-media as challenging (p. 1450). In a more recent study, Shuster et al. (2023) observed that participants in their research have advocated for the inclusion of visual storytelling to enhance engagement

and understanding of complex data (p. 11). Adding to that, advocates of communicative and storytelling information visualization have embraced the ability of figurative images to boost memorability and engagement. They acknowledge that visualizations are frequently created with communication as the main goal, rather than being used purely for analytical purposes (Bryne et al., 2019, p. 46).

Another factor studied is the visual cues or elements. According to one study, appearance judgements of the designers are usually about drawing the eye of the viewer; the engagement aspect of the visualizations (Parsons et al., 2020, p. 178). From the user perspective, Andry et al. (2021) claim that their theme analysis shows that embellishments improve engagement and lower users' perceptions of effort, which improves the reading experience of a visualization. In a previous study Haroz et al. (2015) have found out that pictographs capture initial attention better than simple bar charts, leading to increased engagement with visualizations. In agreement to these findings, carefully designed embellished visualizations are very engaging and they help convey ideas more clearly (Kim et al., 2017, p. 491). Overall, there is a common observation that properly designed embellishments increase engagement.

Sometimes engagement starts during the design process (Christel et al., 2018) For the design of Project Ukko, which is a prototype specifically designed to provide seasonal wind speed predictions for decision makers in the wind energy sector, Christel et al. (2018) have included end users during the design process. Through this engagement, the final design was more successful in terms of involving all stakeholders and bringing in clarity to the uncertainty data. Overall, the end-users were involved more in the decision-making process.

In other times users can be the designers of their own visualizations. In a more recent study, Coelho and Mueller (2020) have designed a tool for non-artist data visualization creators to make use of infomages (short for information images). Infomages are a subset of infographics as defined by Coelho and Mueller (2020); these are casual, context related images in which the charts are embedded into and they also reflect the perception of the data vis designer. When targeting a broad audience, infomages are generally found to be beneficial in communicating data; however, if not used properly, there is possibility that these images become distractions and they may even result in data distortion (p. 594). For novice users and users coming from backgrounds besides design, appropriate use of embellishment may be a problem. Coelho and Mueller's design tool promises to overcome this obstacle and they support their design tool research with a brief usability study. This usability study also revealed the positive impact of embellishments on memorability and engagement (p. 604).

In line with the findings of Coelho and Mueller, engaging visualizations often allow viewers to relate issues to their own experiences or environments. For example, using a map as a visualization can help viewers connect with the data personally (Dörk & Collins, 2013). Allowing users to shape the visualization, such as customizing data representations or leaving annotations, increases engagement. This participatory aspect helps viewers feel more invested in the visualization and the issues it represents. Including personal narratives or biographical information in visualizations can enhance the emotional connection and increase the plurality of perspectives presented (Dörk & Collins, 2013).

On the role of emotions and their relation to engagement Kennedy and Hill (2018) point out that emotions are crucial in making sense of data (p. 830). The emotional

engagements with data are influenced by multiple factors simultaneously such as the data itself, design, subject matter, and participants' abilities (p. 836). Huang et al. (2017) note that emotional engagement plays a key role in sustaining long-term use of tools like Fitbit (a wearable personal tracker). They observed that user interest typically peaks during an initial novelty phase, transitions to routine use, and eventually declines. While their study could not determine if stronger emotional engagement could maintain usage over time, they suggest this as a valuable area for future research. When evaluating users and engagement emotion is not the only way to proceed. Kennedy et al. (2016) argue that contextual, social, and cultural factors affect how people engage with visualizations, making it essential to consider these elements in visualization research.

In short, there are so many levels and factors to consider when aiming for increased engagement in information visualizations. Design elements, storytelling, creating emotional and personal attachment in users, including cultural and social factors are only some of the things to consider.

4.3.3 Aesthetics

Aesthetics is an important measure that needs to be studied since it supports user satisfaction and engagement (Moere & Purchase, 2011, p. 363). According to Moere and Purchase (2011) attractiveness or aesthetics is about "the appeal or beauty of a given solution" (p. 363). It is not only about the visual form, but it also includes vague qualities such as uniqueness, creativity and other factors of user experience. Other studies conducted on information visualizations take aesthetics as the appeal or enjoyability (p. 363). For example, Wang et al. (2008) relate aesthetics with enjoyment and state that a well-designed aesthetical visualization will be more enjoyable and reduce stress (p. 1739). For situations that involve stress, proper color choices that increase aesthetics

would be beneficial for lowering stress and aiding users in creative tasks and problem solving (p. 1740). In further studies, researchers approach aesthetics as attractiveness. Aesthetics is defined as the "subjective evaluation of a graph's attractiveness" (Quispel et al., 2018, p. 239). The aim behind Quispel et al.'s (2018) study is to understand how people's perceptions of graphs may influence how appealing they are. They do not focus on the characteristics of the visualizations that make them aesthetic (p. 239).

4.3.3.1 Factors that Affect Aesthetics

What are the factors that influence aesthetics? Quispel et al. (2018) underline that very little is known about the factors that may make visualizations appealing. Adding to that, the researchers also point out that designers struggle to explain what qualities could make their designs appealing, and design textbooks seldom provide any answer to the question what makes a design attractive. According to a previous study by Quispel et al. (2016) while designers desire a balance between familiar and new designs, laypeople are more drawn to familiar and simple to use designs. For lay people, familiarity and perceived ease of use were important predictors of attraction (p. 247). In another work, "color, form, spatial organization, motion, depth, and the human body" are the six dimensions of visual aesthetics that Peters (2007) defines based on the "modularity" of the human visual system (para. 4). The term "modularity" refers to certain visual characteristics such as color and form to be processed on different parts of the brain.

Clutter, embellishments, clarity and simplicity are among the factors that are investigated by various researchers. Dick (2014) discusses aesthetics in the context of interactive infographics and their design within journalism. There is an emphasis on the debate around "chartjunk", which refers to unnecessary or distracting visual elements in data visualizations. One of the interviewees from The BBC Specials team explains that

they aim for a balance between accessibility and accuracy, acknowledging that while visual appeal is important, it should not compromise the integrity of the information presented. They try to avoid overly complex designs that could intimidate the audience, focusing on simplicity without being reductive (p. 500). In research conducted by Andry et al. (2021) the researchers' aim was to uncover the effects of embellishments on overall assimilation of the knowledge presented in the visualization (similar to sense-making). They have tested two versions of visualizations (embellished and minimally designed) and used semi-structured interview and eye-tracking methods simultaneously to collect data. In their results, the researchers state that almost all embellished versions of the visualizations were aesthetically pleasant, and this also had a positive influence on user engagement. In a previous study, Peters (2007) points to Feininger's claim that the key to a beautiful image is simplicity and clarity in spatial structure. Confusion and disorder result from having too many items in one picture. Additionally, details shouldn't overpower an image. On the contrary, borrowing the idea from Donal Norman, Inbar et al. (2007) claim that complexity does not have to be a negative factor, it might enhance attractiveness (p. 185). Similar to this statement, Franconeri et al. (2021) state that some researchers have found out that viewers who were familiar with crowded charts rated them as appealing, or rated decluttered-charts as too simple and dull (p. 131).

It is also important to note that the studies conducted on aesthetics can be evaluated critically for their test materials. For example, Hill et al. (2018) conducted research on university students and asked them to rank charts with high and low data-ink ratio in terms of beauty, clarity, effectiveness and simplicity. Interestingly the students' ratings were higher for less minimalist (High data-ink ratio) charts. Although the researchers did not evaluate the reasons behind these results, they hypothesize that the

higher rating might have been due to familiarity of the viewers with high data-ink ratio charts (Hill et al., 2018, p. 37). The decluttered materials that they have tested were stripped to their lines, with no colors and barely visible data points. However, it is possible to design visualizations without clutter but with some elements of design that could add a touch of creativity and interest.

McGurgan et al.'s (2021) study underlines this need for a balance between clarity and attractiveness from a perspective of the designer. They have revealed, even though graphic designers all had different conceptions of the term, all respondents have been aware of the aesthetics of the graphs they have produced. Some have described their aesthetic objectives using terms like “clean” or “elegant”. The goals of the graphic designers have been “balance”—the notion that a graph maker must compromise between completeness, clarity, visual interest, and simplicity. Nearly all interviewees reported some degree of discontent with the default designs provided in software packages, and several characterized graph-making practices as “heavy-handed” or even unattractive (p. 192). Similarly, Parsons and Shukla (2020) investigate the chart junk (embellishments) debate from the designers’ perspective. According to their findings from conducted interviews with designers, designers seek a balance between clarity and aesthetic appeal. Context is an important factor in determining the appropriateness of chart junk (p. 213).

In a previous study, the view of the designers and non-designers was compared. Quispel and Maes (2013) have asked graphic design undergraduate students and undergraduate students from other disciplines to evaluate attractiveness and clarity of several data visualizations. As a result, they state that designers prefer attractiveness over clarity whereas non-designers prefer standard (unembellished) charts. In conclusion, they suggest designers to also test for clarity and not solely focus on aesthetics. However, in

their further study Quispel et al. (2018) investigates how designers and design handbooks handle aesthetics versus clarity. Their findings suggest that designers put clarity before aesthetics but they also aim for a balance between the two. In alignment with the findings of McGurgan et al. (2021) and Quispel et al. (2018), Shen (2018) argues that graphic designers are well aware of a need to balance aesthetics with functionality and they have the tools (design elements and principles) that can actually make a positive difference in the information design field. In fact, in their study on information flow, Lu et al. (2020) conclude that the creative graphical layer is intended to be more than simply aesthetically pleasing; it is also intended to draw the user in and emphasize the story. Gestalt principles are essential in enabling the inference of the hidden structure of the information flow.

4.3.3.2 Impact of Aesthetics

Zhang et al. (2020) suggest that higher aesthetic quality in visual representations can significantly impact information intake by enhancing engagement, comprehension, and memorability. This is exemplified by the widespread appeal of artistic projects like “Dear Data” (a project by Giorgia Lupi and Stefanie Posavec).

Cawthon and Moere (2007) take aesthetics as a measurable quality rather than a subjective like/dislike issue. For Cowthon and Moere (2007), aesthetic quality should be taken into account just as much as efficacy and efficiency when evaluating visualization approaches. The researchers argue that considering aesthetics at the very end of the visualization development process is one of the problems. They try to find out about the relationship between perceived aesthetics and error rate and speed. Quitting the task is not another point of interest for the researchers. The methodology of their study is taken from website evaluations. The results of the research indicate that the most visually appealing data visualization technique also ranks high in effectiveness, task completion

rates, and low error response times. The researchers' final remark is that aesthetics does not mean putting aside utility. Overall, various researchers have evaluated aesthetics in relation to other measures such as enjoyment, engagement, memorability, clarity and utility.

4.3.4 Enjoyment

As one of the least evaluated measures in literature, enjoyment is usually studied in relation to engagement. Amini et al. (2018) describe enjoyment as "enjoyment as a consequence of cognitive and affective involvement, broadly defined as a pleasurable affective response to a stimulus" (Amini et al., 2018, table 1). "Fun" and "joy" are among the keywords that researchers associate with enjoyment (Sumedh et al., 2024). In a previous study, Saket et al. (2015) discusses the concept of enjoyment in the context of information visualization, specifically examining how enjoyment can impact performance and memorability. According to the researchers the significance of studying enjoyment lies in its positive effect on mental states. Enjoyment elevates mental state, which seems to improve information visualization performance in particular and problem-solving ability in general.

Using immersive VR technology, Romat et al. (2020) have conducted an experiment on the user experience of visualizations. According to their findings, personalization and immersive VR environments have increased the enjoyment quality of the visualizations. Although it may seem superficial, enjoyment in a visualization can actually enhance people's involvement with data by capturing and maintaining their interest (Romat et al., 2020).

In their research on chart junk, Bateman et al. (2010) have asked the participants to rate visualizations for enjoyment and the findings show that users enjoyed embellished

chart compared to non-embellished charts. Kim et al. (2019) found that users derive joy from controlling how their personal data is represented, with personalized visuals boosting both engagement and enjoyment. Participants observed that personalized visuals could effectively show goals and potential impacts, while the unpredictability of the results added to the overall enjoyment (p. 79). Sezen et al. (2020) have evaluated enjoyment in the context of visualizing soccer match statistics. The researchers have observed that the users found the visual appeal of bar charts more enjoyable than numbers only. Therefore, it is possible to claim that enjoyment may come before accuracy in certain situations. In the end, the researchers relate enjoyment to engagement and suggest designers seek a balance between enjoyment and information access (p. 56).

4.4 Goal-Oriented Measures

Goal-oriented measures include actionability and personalization. The common ground behind these measures is to reach the user in such a way that promotes engagement, behavior change or a further act beyond interaction with the visualizations.

4.4.1 Actionability

Huang et al. (2015) define actionability as the "degree to which the insights gained from using a tool can guide future actions". They also state that there are three levels to actionability; low, mixed and high. Low doesn't encourage action whereas mixed informs and reminds about taking action, high encourages action clearly. In another study that investigates the actionability of Covid-19 dashboards, Sorapure (2023) defines actionability in regards to "supporting decision making by providing users with data that they can act [upon]" (p. 270). What is common between these two definitions is that the presented data leads to action but they do not define how the data does that. There are

several aspects to actionability studied across various research to answer how actionability can be achieved.

Data aspect of actionability: Data has a lot of potential to drive positive actions in people's lives and communities. Yet, as experts in visualization and analytics state, an abundance of data alone does not translate into actionable insights. For data to inspire action, it must be "accessible, understandable, and interpretable", enabling meaningful engagement that leads to practical and impactful actions (Huang et al., 2015). Focusing on climate change and actionability, De Caspell and Vasseur (2021) underlines the significance of communicating complex scientific information effectively to overcome barriers to taking action on climate change.

Cultural aspect: Visualizations never stand alone in isolation. They are created and consumed within societies in relation to cultural aspects. Incorporating elements of social comparison or communal goals into visualization tools can enhance actionability. For example, visualizations that allow users to compare their behaviors with peers can motivate changes based on social pressures (Huang et al., 2015). As stated by Adger et al. (2009) actions of individuals are linked to "cultural and societal norms and values". These links are not static and may evolve or change over time. If climate change communication can address these norms and values then they can influence action (Glaas et al., 2017).

Bringing it now and here: According to Huang et al. (2015) designs that encourage behavior change aim to be a subtle and integral part of users' daily life; such as putting reminders as smart phone wallpapers. This was named as an "ambience" strategy that asks for low attention demand but has enough visibility. In another study, before using the app designed by Glaas et al. (2017), focus groups in the researchers' study viewed

climate change as distant in time and space. According to the researchers, this view may reduce the users' sense of urgency compared to other immediate concerns. After using the app and seeing local flood risks, the users felt the immediacy of climate risks (p. 8). Similarly, Herring et al. (2017) argue that climate risk simulations can address the issue of proximity, making climate change risks feel more personal to users and, as a result, the users may find the issue more urgent (p. 92). The researchers state that gaining more knowledge and comprehension of the effects of local climate is crucial for shifting behavioral attitudes and turning them into actions (De Caspell & Vasseur, 2021, p 241).

Focus on user, location and emotion: A possible characteristic of the data that encourages action lies in its quality of persuasion. Pandey et al. (2014) has researched persuasion of visualizations and define persuasion as "a change in attitude" (p. 1). However, in their conclusion the researchers point out that the user's initial attitude plays a key role in the overall persuasion of the visualizations. This emphasizes the significance of customizing visual material to users' initial values. Huang et al. (2015) argue that higher actionability is achieved when visualization tools provide relevant, timely feedback, allow user customization, incorporate social elements, and present data clearly and understandably. Other criteria derived from studies of medical communication experts can be found in Sorapure's (2023) work, and they are: understanding the user and their needs, creating user subgroups to better provide information, having control over information flow, being transparent about the data source and methods used in analysis to ensure trust, providing links for decisions to make, localizing data, using narrative techniques and appropriate visual cues (p. 259). On a similar ground, Ivankovic et al. (2021) highlights the importance of understanding and providing for different user demographics, using maps over charts and tables to provide better understanding of local

information, using narratives to explain trends, providing data sources to ensure trust and ordering information to ease navigation and understanding. These three studies underline related suggestions focusing on the user, the localization, trust and a better understanding. Additionally, as emotions can influence how users understand and use data to support daily decisions, designers must take into account the emotional impact of reading data (Sorapure, 2023, p. 270).

4.4.2 Personalization

Personalization among the least studied measures within the field of information visualization. Personalization can take place in different ways; users can customize a visualization according to their preferences, users can create their own visualizations or users find personal relevance in exploring a visualization. The following studies exemplify these ways of achieving personalization.

Terrado et al. (2022) take personalization as the adaptation of the visualization to individual preferences (such as the dark mode for interactive visualizations) (p. 18). Applying personal preferences, or customization in other words is found to be quite effective. Kang et al. (2017) explain that customization is psychologically appealing because it enables individuals to actively shape a product to reflect their identity, creating a deep emotional connection with the customized item. The researchers have tested wearable health trackers that were customizable and not customizable to find out if there was a difference between them in terms of user engagement. Their analysis revealed that a sense of identity played a mediating role between cosmetic customization and user engagement. Participants who experienced higher levels of customization reported a stronger sense of identity, which was linked to more favorable attitudes and increased intentions to exercise. However, customization alone was not enough to boost

engagement levels. Overall, the tracker has to align with user perception and health goals (Kang et al., 2017).

Romat et al. (2020) found out that individuals find pleasure in creating their own visual depictions of information. Personalizing visualizations can play a crucial role in storytelling by making data more relatable and creating meaningful visuals for personal data representation. Adding to that personalization of data visualization enables non-expert users to put together a creative, relatable, memorable and pleasing visualization (Zhang et al., 2020). To support this claim, Zhang et al. (2020) had created an easy-to-use tool for non-expert users to create custom visualizations, taking desired pieces from any pixel-based image. The users have expressed their strong positive emotions associated with this tool that enabled them to be creative and self-expressive.

Among productive methods, personalization can also be achieved through filtering content in accordance with personal relevance. Herring et al. (2017) suggest that the act of searching for and discovering content on a platform can lead users to attribute personal significance to what they find. For example, actively exploring the country map may foster personal connections to the locations searched. However, their study did not account for this potential personal attachment in their analysis.

4.5 Usability-based Measures

These measures include efficiency and utility, the measures are borrowed from literature on usability studies.

4.5.1 Efficiency

Efficiency is almost always evaluated as the usability of a visualization. What is meant by usability is completing tasks accurately, quickly and through the easiest process

(*What Is Usability?* n.d.). Similarly, the quality of the autonomous experience when using and interacting with the visualization can be assessed to determine the efficiency of task accomplishment (Cavaller, 2021, p15). Efficiency does not have to be about search and find or compare tasks. The initial task of extracting information from the visualization is also included in efficiency studies. As Franconeri et al. (2021) state visualizations rely on human visual ability to efficiently extract information. Via a change in position, areas, length, angle and intensity, users can extract data efficiently in merely seconds (p.122-123). For these researchers' efficiency is intrinsic to visualizations, it makes extraction of data more quickly and accurately when compared to reading or evaluating long lists of quantitative data (p. 130).

Borrowing the term "efficiency" directly from user studies, Forsman et al. (2013) develop a visualization tool for physicians to use when administering antibiotics for intensive care patients. They conduct usability tests to measure effectiveness and efficiency. The researchers argue that the proposed visualization tool is effective because it combines task-specific information with clear visual elements like graphs, colors, and patterns. Usability tests showed improved task performance and increased graph usage, suggesting the tool is easy to learn and may become even more efficient with practice.

Zhu (2007) proposes a comprehensive definition of effective visualization based on three principles: accuracy, utility, and efficiency. Accuracy principle emphasizes that visual representations should accurately reflect the attributes and structures of the underlying data (p. 657). Utility principle ensures that effective visualizations help users achieve specific task goals. The efficiency principle states that effective visualizations should reduce cognitive load compared to non-visual representations.

4.5.2 Utility

For information visualizations, Moere and Purchase (2011) state that utility refers to "functionality, usability, usefulness, and other performance metrics" (p. 362). Borrowing from user experience studies, the researchers claim that utility is evaluated through effectiveness (accurate task completion) and efficiency. When users use data visualization for representing, analyzing, or communicating data, their focus is on how visualization helps in transferring information effectively, which is a necessary aspect of their performance that needs to be assessed. The measure of effectiveness can be characterized as the degree to which users accomplish specific objectives accurately and comprehensively (Cavaller, 2021, p15).

In relation to utility, another study combines clutter with usefulness. According to Ellis and Dix (2007) displaying too much data in a limited space creates visual clutter, which reduces the visualization's usefulness, particularly when the user is exploring the data rather than seeking specific answers. Ellis and Dix (2007) state that a clear understanding of clutter reduction techniques is essential for designing visualizations that effectively reveal patterns and trends within dense displays. In other words, clutter negatively affects utility.

4.6 Relationship Between Measures and Context Dependency

In literature measures are seldom studied in isolation because measures work together similar to principles and elements of design that work together to form a unified work. Just as it is not efficient to examine design elements and principles in isolation, it can also be inefficient and misleading to examine measures in isolation. To increase effectiveness in information visualizations, it is necessary to understand the interconnected and complementary roles of each measure at play. Measures such as

clarity, comprehension, engagement, and aesthetics often overlap and influence each other. For instance, enhancing the clarity of a visualization can simultaneously improve comprehension by reducing cognitive load and making the information more accessible. Similarly, incorporating aesthetic elements can increase engagement and memorability, but these must be balanced with clarity to avoid clutter that could distract the users. As explained in detail in the sections above, finding a balance between several measures is usually the way to go.

When prioritizing certain measures, there may be conflicts at hand. For example, when comprehension is very important as a goal, clarity and accuracy may be prioritized accordingly. The designers might go for decluttered and minimalist designs and these decisions may clash with aesthetics and engagement. Or in other cases, for public communication, such as climate change awareness, engagement and actionability may be really important, whereas one created for expert analysis may focus on accuracy and efficiency. Understanding these interactions between measures is critical for designers who want to create effective visualizations that are not just practical but also connect with their audiences. A balance between visualizations' goals and user needs and capabilities can be achieved through feedback and empirical studies.

Furthermore, the significance of measures vary according to different contexts (Torban, 2021; Popovich, 2021). The studies by DeCock-Caspell and Vasseur (2021), Wang et al. (2018), Coelho and Mueller (2020), and Peña et al. (2020) highlight the importance of tailoring visualizations to specific contexts and audiences to achieve goals and effectiveness. Therefore, it is essential to further evaluate information visualization measures within a specific context. In the light of these conclusions from the literature,

this dissertation takes the climate crisis as a context and aims to create a framework of measures for impactful visualizations tailored for this context.

5. PRELIMINARY STUDY

The preliminary study was conducted with three graphic designers who have experience in information visualization design. The details of the followed methodology are presented in Chapter 3 of this dissertation.

5.1 Findings of the Preliminary Study

There were two parts in the preliminary study. Part I included open ended questions and Part II included rating of selected visualizations. In Part I of the interview, the participants referred to various graphic design elements such as color, text, dimension, white space, contrast…etc. In literature, most of these elements are investigated by researchers from a scientific perspective. One of these elements mentioned by interview participants is color. Color and the "right use" of color (*renklerin doğru kullanımı*) are graphic design elements/principles that were mentioned by all three participants. In literature, color is among the most researched graphic design elements used in information visualizations. For example, Borkin et al. (2013) claim that use of color affects memorability in a positive way.

Use of texts, captions and labels were mentioned by participants d1 and d2. The use of texts was investigated by Bryan et al. (2020). By using eye-tracking methods, they have tested various visualizations that include text-based elements such as annotations, captions, labels…etc.

Dimension is another design property stated by participant d1. d1 specifically underlined the importance of using statistically proportional dimensions of objects in charts. If a chart is showing data with two rectangles, each rectangle should proportionally represent the data value. On this issue, Kim et al. (2017) had designed a

data-driven-guide tool to help designers adjust their creative data visualizations to correctly show data.

Narrative information visualization or narrative story telling in creating visualizations is a measure referred by participant d3. In literature, Boy et al. (2015) investigate the role of narrative story telling in information visualization engagement. Adding to that d3 also emphasized the importance of a systematic approach in designing information visualizations. Systematic approach was investigated by Lu et al. (2020) in their article in which they proposed a concept *Visual Information Flow (VIF)*. *VIF* refers to the systematic structure of an information visualization linking graphic elements to the story and the message of the information visualization. These flows of elements correspond to the introduction, body and conclusion parts of an information visualization. This structure, which could also be called as layout, was also mentioned by d3.

When designing for lay people or the public in general, the participants underlined the measure simplification (*sadeleştirme*). d1 talked about simplification both in terms of design and the simplification of the message (through eliminating unnecessary layers of data). d2 mentioned simplification of the message and the visuals. d3 mentioned the simplification of the design flow and the colors that are used. *Prima facie*, the simplification measure seems to correspond to Tufte's data-ink ratio design guideline. In literature, data-ink ratio has been discussed a lot but not from the perspective of graphic design. For example, McGurgan et al. (2021) conduct interviews with experts (from non-design fields) to understand how graph makers make use of this guideline. They conclude their findings with the statement that a balance in data-ink ratio works best. However, they do not really explain or provide clues about how this balance would be realized. Also, they do not test it for different audiences. Here, a question arises: Would a high

data-ink ratio work for lay people as well? A high data-ink ratio means that majority of the elements in the visualization represent information/data, there are no “useless” or “junk” elements. At this point, a supportive new study conducted with graphic designers could reveal details on how to achieve a balanced data-ink ratio for different contexts and different audiences.

d1 and d3 mention the term “design language” several times and how the designer is responsible for making use of it in information visualization. This term is rarely used in literature. A further investigation of what “design language” means and its use in information visualization may reveal valuable information on creating effective information visualizations. Similarly, participant d1 talks a lot about the existence of “design concern” [*tasarım kaygısı*]. This term could go side by side with “design language” and they need to be investigated deeply.

For some measures, the participants only considered the data part of visualizations. For accuracy and soundness, they only referred to the data values within information visualizations, they did not mention any graphic design elements or properties when talking about these measures. Other measures mentioned by participants are aesthetics (d1, d2, d3), fun (d2), comprehension (d1) and engagement (d2, d3). All these measures have been studied by various researchers and some are listed on Table 1.

For Part 2 of the interview, the rating of the participants varied immensely. They talked more about graphic design elements and why the graphs lacked certain measures in relation to these graphic design elements. They also referred to measures, concepts and design elements such as chart junk, illustration, icons, audience literacy, designer domain knowledge, context, data layers, credibility, chart type, “negative” memorability,

providing data source, data layers, active audience, experience design, hierarchy…etc. Please see Appendix B for all survey results.

The final three questions were aimed at understanding if the participants would provide different answers for a "good" information visualization after being exposed to various visual examples and a list of measures to rank. They were also asked to propose new measures and rank the top 3 most important measures for a "good" and effective info vis (see Table 5.1).

Table 5.1 *The Table Shows the Answers for Questions 7 and 8 of the Interview*

Participants	New measures proposed	1st most important measure	2nd most important measure	3rd most important measure
d1	Simplification	Comprehension	Efficiency	Accuracy
d2	Providing details	Memorability	Soundness	Comprehension (includes speed)
d3	Narrative	Comprehension (includes speed)	Efficiency	Soundness

5.2 Conclusions of the Preliminary Study

Preliminary findings indicate that graphic designers mention various measures for "good" and effective information visualization. They also mention graphic design elements such as color, text, white space, contrast in association with the measures. However, for semi-structured interviews, the answers given by participants were very general. They did not directly relate graphic design elements with the measures. In Part 2, as they talked on specific information visualization examples, they did associate graphic design elements with measures. As participant d3 was answering the semi-structured questions, d3 stated that it would be much easier to talk about visuals rather than talking about information visualization in general. Thus, Part 2 of the interview was much more fruitful.

The participants differentiated information visualization measures from design language and practical graphical design decisions. Actually, they saw the measures as abstract concepts that lead the designer through the decisions about how to apply (design) the language and graphical elements in the practice of designing. The measures of a to-be information visualization were different from the design guidelines of an information visualization. The guidelines were general rules of good design, whereas measures were targets that were set for specific information visualization at hand. The measures are specific qualities of an information visualization work that is closely related with the data to be visualized, the type of audience, the specific subject of data and the aim of the message.

Some of the measures that the participants mentioned were in compliance with the literature, but some could be said to be new ones. The exploratory study pinpointed the relationship of the measures with the context of information visualizations. The relevance of the context of a work to its "measures" is well-known in the design community, but for the information visualization literature, there were few mentions and even fewer studies that linked measures with the context. This result might be due to the fact that the majority of the research studies in information visualization literature are conducted by researchers from data science, cognitive psychology, informatics disciplines where they either tend toward controlled experiments measuring human cognition (Haroz et.al., 2015) or they focus on automation/software (Kim et al., 2017), or definition of the measures per se (Mahyar et al., 2016; Hung & Parsons, 2017; Amini et al., 2018).

6. FINDINGS AND RESULTS OF WORKSHOPS AND SURVEY

Five workshops were conducted with experts in different fields to investigate the measures of information visualizations created in the context of the climate crisis. The methodology of the workshops is explained in detail in Chapter 3 of this dissertation.

6.1 Findings of Workshops 1-5

In this section, the measures elicited in the workshops; Workshop 1 (W1), Workshop 2 (W2), Workshop 3 (W3), Workshop 4 (W4) and Workshop 5 (W5) are discussed. W1 includes academics, graphic designers and sustainability experts. W2 and W3 include graphic designers and W4 and W5 include participants from NGOs. Figure 6.1 shows the first level codes used in the analysis process and Figure 6.2 shows second level codes with measures in literature and measures derived in analysis. The following chapters will present the findings in the light of these figures.

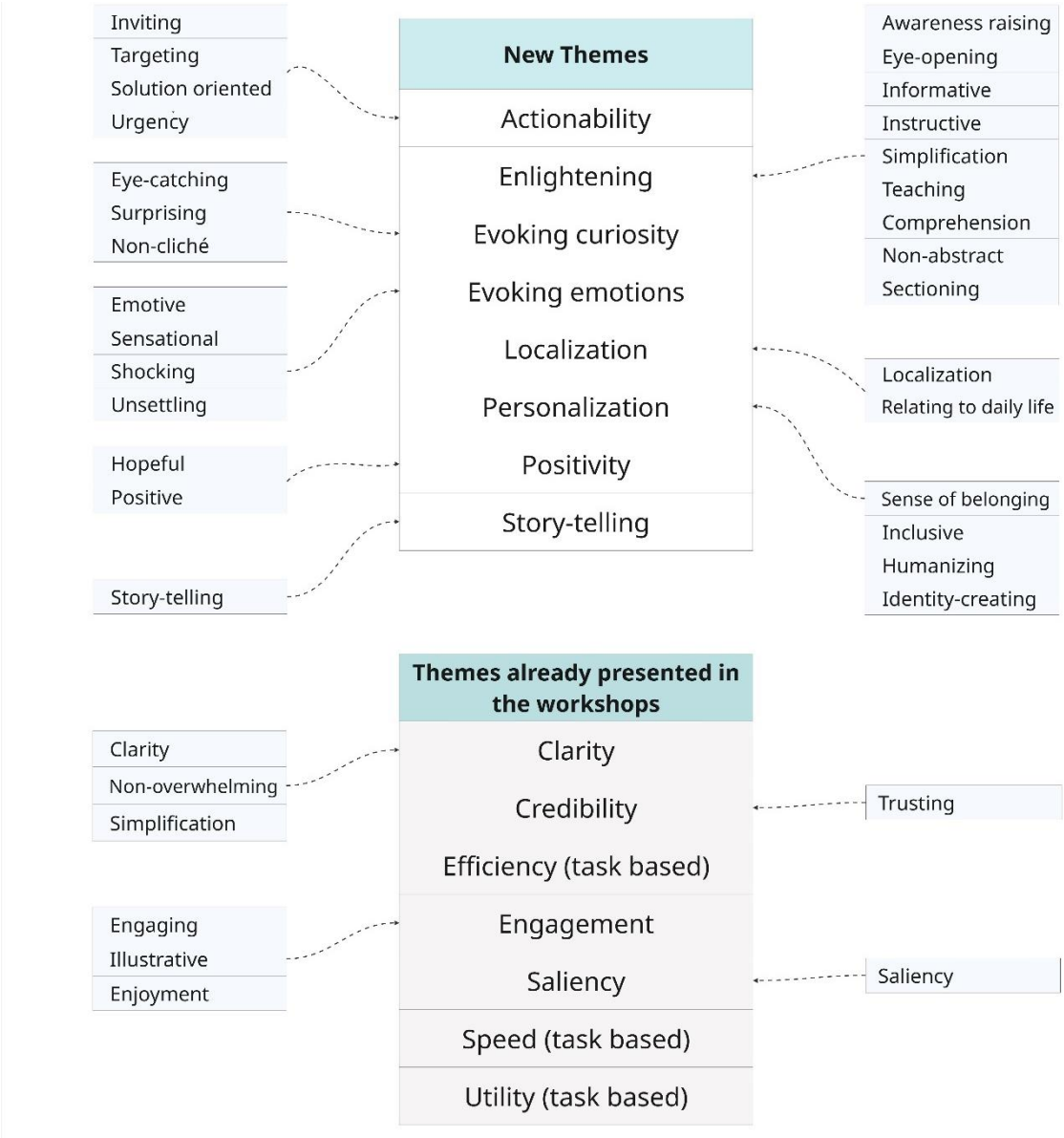
Figure 6.1 *Analysis Process Second Level Codes*



Second Level Codes	W1	W2	W3	W4	W5
Actionability	●	●	●	●	●
Awareness-raising		●			
Clarity		●		●	●
Comprehension		●		●	●
Emotive		●	●	●	●
Engaging		●	●	●	
Enjoyment					●
Evoking curiosity	●	●	●		
Eye-catching	●				●
Eye-opening	●				
Extractibility (Data/info)		●		●	
Familiarity			●		●
Gamification			●	●	
Hopeful	●				●
Humanizing					●
Identity-creating		●		●	
Illustrative	●				
Inclusiveness /inviting			●		
Informative		●			
Instructive	●				
Localization	●	●	●	●	●

Second Level Codes	W1	W2	W3	W4	W5
Non-abstract	●				
Non-cliché	●				
Non-overwhelming					●
Personalization	●	●	●		
Positive	●		●		●
Relatability to daily life			●		●
Revolutionary				●	
Saliency		●			
Sectioning	●	●	●		●
Sensational	●				
Sense of belonging		●			●
Shocking		●	●		
Simplicification	●	●	●		●
Solution-oriented	●	●		●	●
Storytelling			●	●	●
Surprising (hook)		●			
Targeting		●			
Teaching	●	●			
Trusting	●	●	●	●	●
Unsettling		●			
Urgency			●	●	

Figure 6.2 *Themes Derived in Analysis*



6.1.1 Actionability

According to the literature published on climate communication, taking action is regarded to be a component of involvement with climate change on both the personal and public levels. When it comes to the public level, the focus is on societal transformation, and the primary force behind this transformation is the political system (Kumpu, 2022, p. 307). But when it comes to the personal level, engagement is more about overcoming

mental obstacles in favor of behavioral change, such as adopting a way of life that is environmentally conscious and participating in decision-making processes. The majority of the conversations on taking action were centered on the individual level in the workshops.

O'Neill and Smith (2014) highlighted the power of visualizations that show the consequences of climate change in the past and encouraging projections about the effects of climate change in the future. Wang et al. (2018) studied the effects of visuals and imagery on the engagement of general audiences in the context of climate change communication and concluded that images have a key role in public engagement. The researchers also underlined that there is no single solution for creating these visuals, as different goals and different audiences call for varying approaches.

Participants proposed utilizing realistic images to illustrate the risk and negative effects of climate change (W1), which is in accordance with the findings that have been found in the literature about climate change. It was claimed that artificial intelligence technology may be utilized to generate visualizations of potential future scenarios. Creating a feeling of urgency and highlighting the scale of the climate problem may be achieved by visualizing potential future scenarios, such as the rise in sea levels and the impact it will have on the local topography. Furthermore, it is argued that the use of realistic images can assist non-experts in visualizing the negative effects of climate change. This discovery is comparable to the findings of the study conducted by Ballantyne et al. (2016), which demonstrates that visual representations are beneficial in terms of explaining climate change data, assisting lay people in gaining a tangible knowledge of the issue, and providing a viewpoint to comprehend the uncertainties that are inherent to climate change (p.83). The overarching goal is to incorporate compelling

visuals that will not only captivate the viewers but also improve their comprehension of the effects of the situation. Participants expressed their belief that images had the potential to magnify the consequences of the message. The use of imagery that is both strong and fascinating has the potential to create feelings, which may then lead to an increased motivation to take action.

Related to the *actionability* theme, there were two additional components that were included: inviting (W3) and targeting (W2). It was noted by one of the participants that in order for an information visualization to be inviting it should pose a question. Questions encourage the audience to contemplate the matter at hand and to take part in it by considering the response to the question (W3). It is possible that audiences may be motivated to take personal action on climate change as a result of this reflection, which might potentially build a sense of engagement. On the other side, a targeting component could also be a triggering factor for action. It is possible that information visualizations that contain clear and focused messages are leading the audience in the direction of issues that they may take action on. For instance, audience members can be directed toward this particular issue through the use of an information visualization that focuses on the environmental effect of the production of meat and dairy products, which makes it simpler for them to think about taking decisive actions (W2).

Another category related to this theme was about being solution oriented (W2, W4, W5). According to the participants, showing solutions was much more important than showing cause and effect relationships. In order for people to act, visualization should focus on providing solutions, guiding the way and also promoting some hope. The participants underlined that the role of the individual in the solution part should also be shown clearly (W4, W5). Providing hope, showing societal and human consequences of

the climate crisis and creating a channel for individual and organized action are among the priorities of climate crisis communication (W4). Hope is also underlined for motivating individuals to keep going with climate mitigating actions. Losing hope is associated with quitting, letting go and underestimating the influence of the individual (W5).

Creating or communicating urgency is another notion that is related to actionability (W3, W4). Climate crisis has been a slow but constantly ongoing global issue. It is very easy to see it as distant in time and space (Glaas et al., 2017). However, the IPCC scenarios are showing that the climate crisis is affecting our world much faster and more impactful than our previous anticipations (Kurnaz, 2022). Participants in W4 stressed this as "These are systems whose results we cannot see directly, systems that work slowly, systems that work slowly throughout a lifetime… but we are currently in an extremely accelerated situation. Therefore, we can also focus on these speeds, accelerations, and time".

Besides these categories, throughout the discussion in W2, appealing to emotions were discussed in relation to various themes. In the case of actionability, reaching out to "blind emotions (*kör duygular)*, such as fear" could be beneficial for motivating individuals into action. Emotions are so powerful that they make up a theme which will be discussed more in detail in Section 6.1.4.

6.1.2 Enlightening

The theme *enlightening* includes several categories: informative, eye-opening, instructive, simplification, sectioning, teaching, comprehension, non-abstract and awareness raising. Although these categories seem diverse, the common theme that binds

them together is providing information to create or increase knowledge on the climate crisis.

By informative, what was discussed by the participants in W2 was about providing the information for those who do not know it. And the way information should be explained is to "explain as if you were explaining to a child" (W2). Participants in W1 had a slightly different perspective on informative quality. Providing information for those who do not know the consequences of their daily actions or providing information on indirect effects of "buying a pair of jeans or gifting gold coins in weddings" were given as examples (W1). It was underlined by the participants that the informative quality should not only provide information, but also develop knowledge of the greater implications of everyday habits to encourage more thoughtful decision-making. Disrupting the everyday habits, correcting habitual behaviors are also eye-opening for the public (W1).

The notions of simplifying, clarifying, and clearly explaining aspects, as well as avoiding excessive terminology, were crucial topics that were covered in both W1 and W3. There was also a discussion about the topic of simplicity in relation to the language that is utilized within data visualizations. In order to facilitate better comprehension, it is recommended that communication be kept within the framework of everyday language, without an excessive amount of emphasis placed on domain terms. In accordance with the findings of Wu et al. (2023), which imply that professional and complicated language should be transformed into ordinary language, this is done in order to ensure that lay audiences are able to understand the issue and that an emotional resonance may be established.

Sectioning is a supportive method related to all of the above-mentioned categories. In almost all workshops (W1, W2, W3 and W5), sectioning or layering information was discussed. Sectioning is about dividing big chunks of information into digestible small parts (W2 and W3) This is in line with the scaffolding method of dividing information into chunks explained by Majooni et al. (2017). One of the participants gave an example of to-do lists for sectioning. “In daily life, to organize our chores and work we use to-do-lists, so that what we need to do is less overwhelming for us” (W2). Adding to that, a participant from W3 noted that they would divide a design brief into smaller parts to start working on it. With this method they would differentiate what is more important and what is less important and which parts can be left out (W3). Here, the same principle applies, dividing information into its part to not to overwhelm. This makes comprehension much easier for the audience. Sectioning is also about dividing the data chart into parts if there is an information overload (W5). Layering is another method that is similar to sectioning. According to two workshops designers should layer information to aid comprehension (W1, W2). Layering means dividing the information into a few successive layers, simplest facts come first, and complex information piles up one layer after another. A participant from W1 gave this example: To provide information about the decrease in yearly rainfall per square meter, an information visualization may be used to highlight the link between declining harvests and decreasing rainfall per square meter, and then connect those decreasing harvest rates to the scarcity of food. Information can be built on top of another to provide consequences of initial information.

Teaching quality of a visualization depends on the context. The issue of the climate crisis is a complicated one; the reasons behind it are intertwined and the impacts of it are widespread and complex. According to the findings of the first and second

workshops, the lay audience is seen as oblivious to the issue. Taking this view on the users in consideration, “Foolproof visualizations” (W2) and “designer’s awareness of the level of ignorance” (W1) were stated as essential for designing effective information visualizations considering the climate crisis.

Although comprehension in literature is a measure widely discussed, it was approached as a category for this dissertation. In workshops comprehension was discussed as a step towards enlightening the audience therefore it is not considered as a theme in analysis. On comprehension, the audience's numeric literacy was discussed in Workshop 2. One of the participants stated “to help the audience understand how much the prize of the lottery is, the TV channels used to show how many cars you could buy with the prize money… the public cannot comprehend [big] numbers (W2). Similarly, the volumes, and sizes present in climate data are hard to grasp for human scale. A designer can visualize quantitative data in a relatable, tangible and non-abstract way. The concept of 100,000 hectares of forest can be difficult to grasp, but illustrating it by equating this area to the number of football fields can help lay audiences better understand the scale (W1). Presenting data with metaphors, thus making concepts more tangible and non-abstract by use of correct metaphors was also discussed in W3 “...explain the results of [climate crisis] by illustrating tangible results such as draughts, floods, heat waves” (W3). Making comparisons can also increase comprehension (W1, W2); such as comparisons between years or between countries can aid the audience understand the trends and differences in data. Adding to that, designs that are clutter free and make use of color in accordance with the message or data increase comprehension (W4). A final aspect to consider in comprehension is missing information, labels or annotations that create an obstacle for the audience to understand charts (W5).

A further category, awareness-raising, is similar to informing but the participants had specifically differentiated it. While informing focuses on delivering facts in a straightforward manner, awareness-raising is about engaging the audience on a deeper level and including surprising information. After reviewing an information visualization about the countries that contribute most to ocean pollution, one participant expressed surprise and found the data highly engaging. This engagement, he noted, “led to an increased awareness of the issue on his side” (W2) (see Figure 6.3). The figure lists countries that most pollutes the oceans as Philippines, India, Malesia, China, Indonesia, Myanmar, Brazil, Vietnam, Bangladesh and Thailand.

Figure 6.3 *The Countries that Pollute the Oceans the Most with Plastic Wastes*



Source: Doğru Veri, April 10, 2023, Retrieved from https://www.instagram.com/p/Cq2TAxboA2T/?utm_source=ig_web_copy_link .

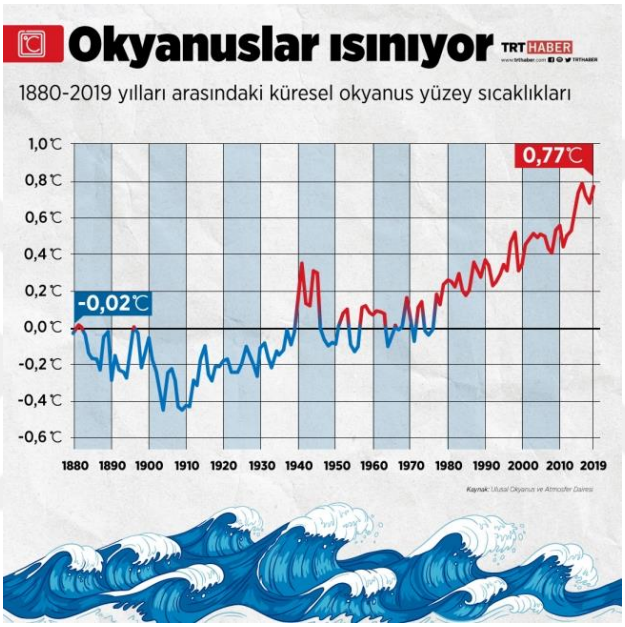
6.1.3 Evoking Curiosity

The issue of climate change has been discussed in the media for several decades now. Information visualizations on the topic are widely available. A number of participants in W1 pointed out that some visualizations, such as fish swimming in a lake bottom that has been cracked and dried out, or a bird strolling on a land of deforestation, have been used so frequently that they have become "cliché." These kinds of information visualization designs might cause consumers to become uninterested and unresponsive in today's world. They borrowed the idea from the phenomenon of ad-blindness on the web and suggested that people are becoming increasingly indifferent to the effects of climate change. Making use of analogies, illustrations, and graphic styles was their recommendation for coming up with creative methods to visualize information.

A suggestion included an illustration created for an information visualization on the consumption of vast amounts of water to produce one liter of cow's milk. The use of a hand-drawn illustration of a dairy cow having a bath in a tub was suggested by one of the participants. This would not only attract the attention of the audience, but it would also emphasize the significant amount of water that is necessary for production of milk (W1). Using hand-drawn lines and a typeface that is similar to handwriting would make the overall design feel more personal and intimate, thus encouraging an individual to engage in personal engagement on the matter. Another participant made a comment that was quite similar to this one, and it was about the need of developing a visual hook in order to attract the attention of the audience (W2). In light of the fact that people's attention spans are getting shorter, a surprising hook in the design would be to attract the audience's attention toward the information visualization.

Participants in W5 referred to design language and how visual tricks or visual metaphors can be eye-catching. For example, if the context is about the oceans, a visual play with waves can make an information visualization stand out (see Figure 6.4).

Figure 6.4 *Oceans Are Warming: Global Ocean Surface Temperatures Between 1880-2019*



Source: TRT Haber, June 16, 2020, Retrieved from https://www.trthaber.com/haber/infografik/okyanuslar-isiniyor-493377.html .

W5 participants evaluated this in favor of enjoyment but for participants of W2, evoking curiosity was a notion to follow instead of enjoyment. The climate crisis is not a "fun" or "enjoyable" issue but enjoyment of experiencing a visualization can be achieved through curiosity (W2). For example, a large countdown displaying a phrase "only 500 days left" may intrigue the audience into asking questions and grab their attention.

6.1.4 Evoking Emotions

In each of the workshops, the emotional impact that the visualization design had on the audience was brought up as an important topic of discussion. The reason for this

is that “works that trigger emotions get more reactions” (W2) and “people bond with the subject” (W3), as well as the possibility that “[emotions] activate people” (W3). The samples that targeted emotions were described as “sensational” (W1), “optimistic” (W1), “depressive” (W3), “disgusting” (W3) and “frightening” (W2), respectively. These samples were successful because they addressed emotions specifically. The participants said that the aforementioned feelings were created in the information visualization examples by the utilization of a color palette, the content of the images, and the word choices that were made in the texts. Discussing emotions and storytelling, participants in W4 highlighted “empathy”, “storytelling enables a person to see themselves in a situation created as the consequence of climate change”.

Although emotions were discussed in all workshops, there was no agreement among the participants about which emotions should be focused on. W2 participants argued that targeting “blind” emotions are key to creating effective visualizations and fear is the typically included emotion. W4 participants evaluated visualization that counterbalanced fear with softer, pastel colors positively. W5 participants underlined the importance of appealing to positive emotions and not focusing on dark emotions so much since “bad emotions might cause depersonalization”. On the other hand, participants in W1 came to a consensus about the need to avoid fear since it provokes eco-anxiety, which in turn leads individuals to give up on their efforts. Even though W3 participants did not recommend the usage of any particular feelings, they emphasized that the designs should surely contain emotional components in order to establish a bond with the audience, to successfully transmit messages, and, lastly, provoke responses from individuals.

6.1.5 Localization

All of the workshops agreed that localization is an effective tool that should be taken into consideration when making design decisions. During the W3 discussion, participants claimed that the communication technique that had been used in the previous years had been unproductive since there were scarce local implications visible. They said "...The photos of polar bears swimming in melting arctic ice, caused the climate catastrophe to be regarded as a problem that was far away...We need to make use of the metaphors and pictures that are available here" (W3). The same idea was also stated in W5, one participant said "melting of the ice is not only happening in the arctic region, it is also happening in the Kaçkar Mountains". With this statement, W5 participants highlighted that messages that are supported with local insights (*yerel içgörü*) would close the distance gap between the idea of the climate crisis happening elsewhere and the effects of climate crisis felt right at home.

For the purpose of localization, it is recommended in W1 to make comparisons between our country and other countries. Comparisons of geographical locations can be helpful for non-specialist audiences in understanding the situation in their own nation or city in relation to the situation on a global scale. In addition, there are findings that support the effectiveness of localization. DeCock-Caspell and Vasseur (2021) discovered that people were more involved and were able to appreciate how the climate issue is hurting the ecosystem after seeing aerial photographs of their local shoreline. In the photographs, the rise of the sea level was indicated with drawn lines to show the old shoreline of the past years. The people could compare the new shoreline with the old ones in the same image. In terms of their comprehension of the climate crisis, it is possible to claim that individuals from different nations have comparable characteristics.

Another way of localization is to choose the best images that resonate with the audience. Evaluating one of the images provided in the workshop discussion, a participant criticized the use of foreign signage taken from another country (W4). The image was a depiction of flood waters submerging a traffic sign of pedestrian crossing (see Figure 6.5). The suggestion was to use a local traffic sign or to use images of floods directly taken from our country. This way, the audience would engage or connect with the image and the message more effectively.

Figure 6.5 *63% of Us Associate the Increase in Unusual Seasonal Events with the Climate Crisis*



Source: Yuvam Dünya, March 29, 2023, Retrieved from https://www.instagram.com/p/CqYA_BkqiXR/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA== .

As a notion, connecting with current dialogues, popular current themes and the language of daily life (e.g. "*güncelle bağlantı kurmak*, *günlük konuşma diline girmek*")

was emphasized over and over in discussions in W5. They referred to local examples such as people keeping track of water levels of dams in Istanbul during summer, or the craze of Dubai chocolate. These current discussions can be utilized to connect the audience with the effects of the climate crisis. The lack of rain and the resultant low water levels or the possible extinction of cacao beans in near future are possible points of connection between popular daily discussions and the climate crisis (W5).

6.1.6 Personalization

A sense of belonging (W2, W5), inclusiveness (W3), humanizing (W5), identity-creating (W2, W4) and focusing on the individual actions (W1) are notions that promote personalization. The establishment of a link between the individual and the climate problem can be accomplished through the creation of a sense of belonging ("*aidiyet duygusu yaratma*") (W2). For the purpose of establishing a personal connection to the environment and, as a result, inspiring a sense of responsibility and desire to engage in sustainable acts, situating the audience as a part of their neighborhood, and then expanding to the city, the country, and finally the Earth, might be an effective strategy. Closely related but somehow different, W5 participants matched the sense of belonging with the idea of viewing Earth as our home (that also resonates with their NGO name *Yuvam Dünya*). While W2 participants wanted to match belonging with more local elements at first (e.g. the neighborhood), W5 participants wanted to immediately connect the audience with the world.

The neighborhood concept or the viewing of the world as home (i.e. one global village) can be related to inclusiveness. One participant in W3 stated that being inclusive, and not pushing people away from the issue is quite important. Regardless of their political views, the messages should include everybody. This inclusiveness can also be

supported with a design style that is intimate (e.g. handwritten fonts, illustrations) to help to connect the message on a personal level for everyone. Similarly, a participant in W1 also commented on keeping clear of reflecting any political views of groups. This view is placing the climate crisis above and beyond daily political agendas.

It is important to be inclusive and as doing that humanizing the visualizations can be a method to proceed with. What is meant by humanizing by W5 participants is to include more human images to help create a connection with the issue to the audience. This is in line with the idea of including human recognized images in visualizations to promote more engagement (Borkin et al., 2016, Coelho & Mueller, 2020). Since the materials presented at the workshops were mainly from social media, including visuals of the humans are known to increase social media interactions. Use of human images would not only increase likes and shares but also create a mental connection between humans and the climate crisis in the minds of the audience.

A personal connection can also be made through identity creation. W4 participants underlined that without creating an identity such as being an environmentalist, the messages received from a visualization have no purpose. What is learnt is what is learnt and that's it. If an identity is created this can lead people into action. From an advertising perspective, W2 participants referred to another aspect of the identity. A “cool” image or identity should be developed to promote action against the climate crisis. As the advertising world was promoting an image or identity by connecting it to using a product such as “drinking Coke is cool”, the same tactic should be applied to the climate issue (W2).

On top of that, the specialists in W1 highlighted the significance of individual acts, even if such activities seem modest in comparison to the magnitude of the problem. In

W1 and W2, it is stated that providing people with an explanation of the bad consequences that are caused by something that they do on a daily basis might make it easier for them to relate to the climate crisis. It is possible for lay audiences to become aware of the role of the person and look for answers if they are presented with a comparable act. An everyday example (W2) is a straightforward representation of the layers of a hamburger and the quantity of water that was used to manufacture each layer. The picture is intended for those who are not scientists because of its straightforward appearance (see Figure 6.6)

Figure 6.6 *How Much Does Your Food Cost the Planet?*



Source: Istanbul Climate Save, July 30, 2023, Retrieved from https://www.instagram.com/p/CvU5RKJIPeR/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA== .

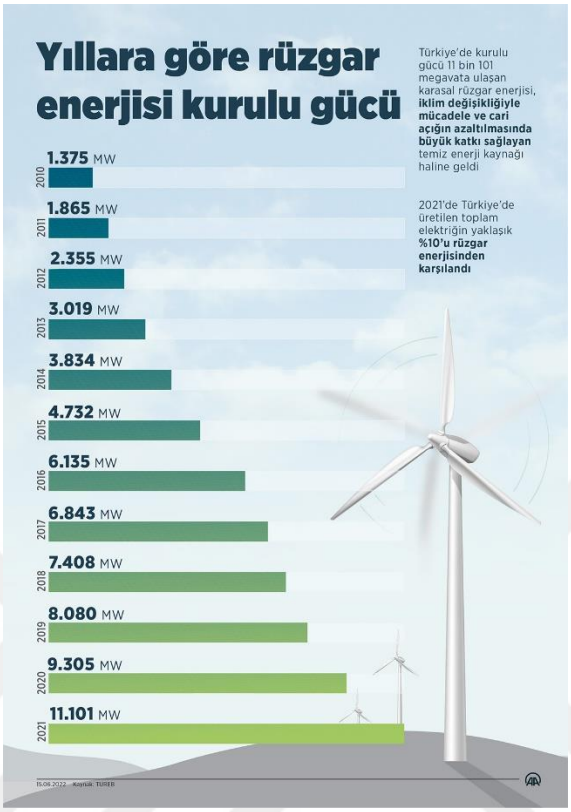
The content of the graphic corresponds to the consumption patterns of people who eat at fast-food restaurants in Turkey; according to Deniz and Abbasaliyeva (2022), 59%

of people who dine at fast-food restaurants in Turkey prefer eating hamburgers. Relating to daily life was also mentioned by participants in the third workshop. By providing examples from daily life, an information visualization may enable the audience to connect with the issue on a more personal level (W3). Real stories from everyday life, even very simple acts of recycling may help audiences to see that every personal action counts and the individual can make a positive impact with even small contributions (W3).

6.1.7 Positivity

The participants in W1 and W3 stated that when communicating climate change to lay audiences, it is important to maintain a design language that is optimistic and positive. They emphasized the fact that when confronted with the hard reality of climate change, maintaining a positive attitude may be a highly effective technique for avoiding any potential adverse emotional impacts, such as eco-anxiety (W1). When people become aware of environmental issues, they may experience negative emotions such as tension, helplessness, fury, or despair. These feelings are commonly called eco-anxiety. It is likely that maintaining optimism will encourage sustainable behavior, as opposed to bombarding lay audiences with the implications of the climate crisis and emphasizing on possible answers and activities might be more effective. The participants made a comment on one of the visualizations that “this visualization concentrated on achievements rather than cautioning about the implications this is a positive information visualization” (W3). This was one of the positive examples that was pointed out by the participants (see Figure 6.7).

Figure 6.7 *Installed Wind Energy Capacity Per Year*



Source: Anadolu Agency, June 15, 2022, Retrieved from https://www.aa.com.tr/tr/info/infographic/28630

At this point positivity seems to clash with urgency of actionability and evoking impactful feelings such as fear to make people take the issue seriously. Maintaining a positive attitude does not imply ignoring the importance of the issue or the sense of urgency it presents. As a matter of fact, designers are required to achieve a delicate equilibrium between positivity and a sense of urgency (W2). In order to ensure that lay audiences have the motivation and empowerment to act upon the knowledge that they gain from the data visualizations, it is important to frame the communication in a way that is constructive and actionable.

6.1.8 Storytelling

Storytelling was widely discussed in W4. Telling a story through data is a method that can reach lay audiences. The participants expressed that they pay special attention to

this narrative component in their communication materials. Also, as they evaluated the visual materials, they discussed how some of the design decisions were promoting the storytelling for each case. In W3, the participants also briefly talked about storytelling as a way to create an emotional connection with the audience. In connection to the humanizing category, W5 participants also mentioned storytelling as in including real stories of real people in visualizations and in communication. Although every workshop holds the issue from different points, overall, the expected impact of storytelling is to increase engagement. The relationship between storytelling and engagement is also significantly debated in literature by Boy et al. (2015), Schuster et al. (2023) and many other researchers. They have provided extensive evidence that storytelling increases engagement.

6.1.9 Clarity

Being simplistic (W1, W2, W3, W5), clear (W2, W4, W5) and non-overwhelming (W5) were concepts that appeared in the research since the very first preliminary study. As discussed in Chapter 5, all of the participants of the preliminary study mentioned clarity and simplification while designing for lay people or the general audience. To briefly recite their statements: d1 discussed simplification in terms of both design and message simplicity (by removing superfluous data layers); d2 talked about the images and the message being simplified and d3 talked about the usage of colors and information flow in a simplistic manner.

In workshops, during all workshops the participants mentioned simplicity in relation to clarity. Among the evaluation materials, an information visualization providing a single data, one numerical information with an image that supported it, was well received by a participant of W4. The participant stated this composition as simple

(*yalın*) and claimed it provided a clear focus. It was easy to understand and the large text showing only one percentage was engaging. Similar evaluations were also made by W2 participants. While they were assessing the visual materials, they found simplistic designs, visuals showing single charts as straightforward and clear. Another participant in W3 said "On the contrary to other examples, it is a normal pie chart, there is nothing else involved, and since it is a simple and familiar usage, the message is given directly". This participant also mentions the familiarity of the chart type and simplicity of the design that added to the clarity of the message.

Being clear about the message is also possible through the simple use of language. W1 participants underlined the significance of using a simple, terminology free language to help the lay audience understand the issue at hand. "Simple explanations, simple lines in illustration" were among their statements.

Evaluating Figure 6.7, a participant from W5 criticized crowded content and look of information visualizations. They said "I am always looking for such simplicity… frankly, we don't read too much about something on social media". Again, targeting social media, overcrowded images, too much text in design are things to avoid. The scrolling down action in social media is very fast and looking happens more than reading. Therefore, as suggested by a participant, the charts should be divided if there is too much information (W5).

6.1.10 Credibility

Credibility is extensively talked about in all workshops and was expressed as trust and trustworthiness of the data and the information visualization as a whole. In terms of data, some participants had questions about whether the data shown was correct or made-up (W2). In W3, a participant made a differentiation between data coming from

governmental sources and other private corporations. If the data was coming from a corporation this could be just green-washing (a term also used by W1 in discussing sustainability efforts of institutions and private companies). Green-washing of a company would undermine the trust of the data, and if the style of the information visualization looks similar to a corporate design of a company, this could lead to distrust (W3).

The design style of an information visualization includes various elements. For example, a participant in W4 talked about font choice to ensure trust in a visualization. They said that fancy fonts can be used for the titles but for the main part, serious looking ("*ciddi görünen*") fonts should be used. A similar remark was made in W2 this time about the color choices. The participant in W2 said "Less colors, a simple design always provides trust". W3 participants also agreed with the importance of font and color selection. Here, a contradiction takes place between trustful simple designs and engaging illustrative designs. This contradiction is very similar to Tufte and Holmes disagreeing about the data-ink ratio explained in section 4.3.1.2.

The source of the information visualization also changed the view of how participants assessed the visualization. A participant in W4 was evaluating the information visualization's lack of storytelling but after looking at the logo of the news agency, they said "it is not expected from this agency anyways". The participants had a bad impression of the news agency and the logo on the visualization made them lower their trust and expectations about the effectiveness of the visualization design. On the opposite end, a participant from W5 made a positive comment because of the logo of the institution they saw on the information visualization. They said "I can trust this data because it is taken from NASA and translated into Turkish by the news agency". In W2, the source was given a lot of significance that they said "[they] would put the source right

at the top with larger punto, they would not write it small like a footnote". The importance of showing the source of data was also underlined in W3 and W4 as "critical". The views of the experts in workshops align with literature as Kennedy et al. (2016) and Mary et al. (2019) state that source credibility is crucial to information trustworthiness.

6.1.11 Engagement

Engagement plays a key role in the effectiveness of information visualizations, as it draws viewers' attention and promotes a sense of curiosity. Elements such as illustrations, color use, and the inherent appeal of the data itself are important in capturing audience interest.

Illustrations which were despised by Tufte (1990) but found to be engaging by several researchers (Kim et al. 2017; Andry et al., 2021) were discussed under the category of engagement in W2, W3, W4 and W5. Among the 104 provided information visualizations there was one that showed an illustration of a man with glasses, drawn in a very sketchy manner (see Figure 6.8).

Figure 6.8 *How Do Extreme Heat Events Affect the Human Body?*



Source: Change.org Türkiye-iklim,August 21, 2023, Retrieved from https://www.instagram.com/p/CwMjvcvoF6f/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

This visualization was selected by many participants to evaluate for different measures. A participant in W2 found the man in the illustration "funny looking and standing in a funny position. That's why it is grabbing our attention". Another illustration that grabbed the attention of the participants (W5, W4 and W2) was the flat illustrations of bees. The bees and the interesting phrase in the title of the information visualization (The false spring delusion of bees/*arıların yalancı bahar yanılgısı*) received many positive comments from the participants. It was found both interesting and also intriguing as "false spring" is a subject unknown to many (see Figure 6.9).

Figure 6.9 *The False Spring Delusion of Bees*



Source: TRT Haber, February 1, 2023, Retrieved from https://www.trthaber.com/haber/yasam/arilar-yalanci-bahara-aldandi-bal-uretiminde-dusus-bekleniyor-742554.html .

Colors are found to be also engaging by the participants in W2, W3 . A participant said "Trying to explain something with color is an interesting thing, I think it is very effective and simple, it is not such a complex thing, it is a tool that can explain things well" (W3). Improper use of colors or mixing too many colors were also criticized for decreasing engagement (W4, W5).

The data itself can also be engaging. "It is important that the data is interesting at this point. For example, I think a very good example of this is the Climate Stripes, which symbolize the increase in temperature" (W5). Only showing a single point of data, in big capital letters is also found to be engaging (W5). The single number or a percentage would draw in the viewers by making them ask what it is about.

6.1.12 Saliency

For saliency, participants in W2 mentioned using color and text to create a focus on important information in the visualizations. As a matter of fact, the same elements, color and text, were mentioned as utilized tools for creating saliency by Franconeri et. al. (2021). Even though other workshops did not directly talk about saliency, they talked around the term with evaluating information visualizations as "attracting the eye to a point" on the composition. The discussions around visualizations that showed only one data point or percentages with larger text can be considered as designs applying the saliency measure. With large text right in the middle of the image both evokes curiosity, increases engagement and guides the eye to this important data (saliency). Therefore, saliency works together with other measures in a well-composed information visualization. In literature, it is also related to increase in task speed (as saliency guides the viewer, viewer finds relevant information faster). Franconeri et al. (2021) has revealed that adding direct labels to information visualizations has increased speed. Direct labels guide the viewer to salient information and viewers find what they are looking for faster.

6.1.13 Graphic Designers vs. NGOs

There were categories that were common to all workshops and there were actionability, localization and trust. Creating emotions and presenting information in segments were agreed upon by participants of four workshops. Then, clarity, comprehension, engagement, storytelling, simplification, solution oriented, evoking curiosity and personalization followed the common categories with three workshops mentioning them each.

Putting aside W1, which included diverse experts, W2 and W3 (graphic design experts) and W4 and W5 (participants from NGOs Greenpeace and *Yuvam Dünya*)

showed common points of emphasis with respect to their professional fields. The graphic designers mostly focused on the message and how design can effectively give that message. The NGOs mostly focused on communication strategies (e.g. storytelling) and turning communication into a tool that would promote taking action (actionability). Overall, the comments of all workshops (2-5) complemented W1 comments.

All the workshops were converged on the following aspects:

Actionability: The same as graphic designers, NGOs also stressed on the fact that audiences should be directed to taking action. Both the groups stated that the visualizations should not only present information but also enable people to take action about it. NGOs emphasized solution-oriented designs, showing pathways for individual or collective efforts and increasing hope as a counterbalance to fear or eco-anxiety.

Localization: All the workshops stressed on the relevance of making the data more local to the audience. Some of the examples that were given include the use of local symbols or problems in order to make the concept relevant and timely.

Trust and Credibility: Both sets of participants highlighted the reliable sources and the trustworthy design elements such as the fonts used, the layout and even the sources of the information (logo of the information visualization creator).

Graphic Designers' focus (W2 and W3) was more from the angle of message transmission and design effectiveness:

Clarity and Simplicity: Designers prioritized visual clarity, minimalistic layouts, and familiar formats (e.g., pie charts or single data points). They emphasized that simplicity helps audiences grasp key messages quickly, especially in fast-paced environments like social media.

Engagement vs. credibility: Designers discussed the line between engaging design with illustrations and colors and the need for credibility. They acknowledged that very artistic or stylized designs are catchy but can lower perceived trust.

Evoking curiosity and Engagement: Designers were interested in increasing curiosity and engagement through metaphors, illustrative storytelling, or playful typography. For instance, they have suggested designs that use humor or surprise (a cow in a bathtub to represent water consumption-to draw attention).

NGOs approached the topic with a strong focus on communication strategies and audience impact:

Storytelling: The participants from NGOs underlined the narrative as important to create an emotional connection and engagement. They wanted to include real-life stories or scenarios that could humanize the climate crisis and make the message personal.

Inclusivity: Most of the NGO participants stressed making visualizations accessible and inclusive to diverse audiences. It should avoid political polarization and be in a form that all people in the society can relate to.

6.2 Results: Towards a Conceptual Framework

This section discusses the findings of the survey conducted with expert designers to validate and rank the most prominent information visualization measures for climate change communication. The survey asked participants to evaluate a series of identified measures on a 5-point Likert scale for each of three overarching communication goals. As explained in Chapter 3, these goals were: Goal 1- Ensure Trust through Reliable Information, Goal 2- Connect with Stakeholders with Clear, Inclusive, and Solution-Oriented Communication**,** Goal 3- Mobilize Participation with Urgency and Hope. Participants were then prompted to select three measures they found indispensable for

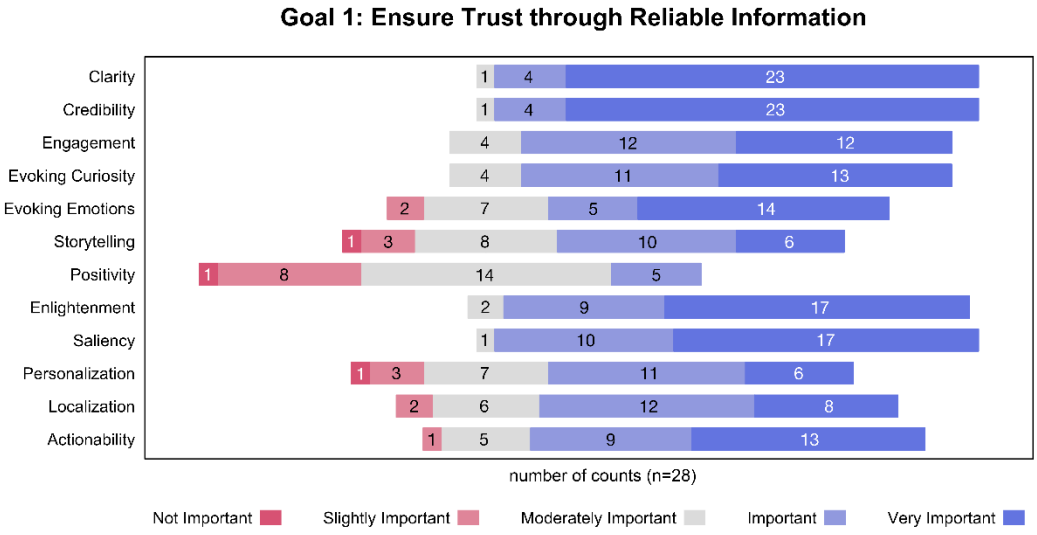
each goal. An additional step asked participants to choose three overall indispensable measures across all goals.

The visual analysis of the survey responses reveals both consistencies and divergences in perceived importance of different measures depending on the communication goal. The discussion below evaluates each goal individually and concludes with a synthesis of cross-goal findings.

6.2.1 Measures for Goal 1: Building Trust Through Reliable Information

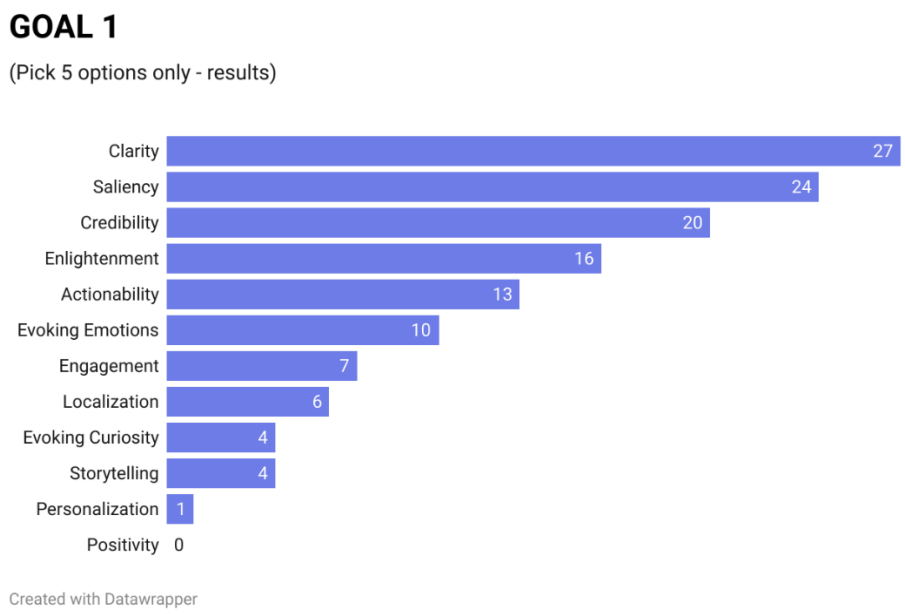
For the first communication goal – ensuring trust through reliable information – participants' ratings converged on a clear set of top-priority measures. The five highest-rated measures (as rated most important on the Likert scale) were *Credibility*, *Clarity*, *Enlightening*, *Saliency*, and *Evoking emotions*. In particular, *credibility* of the information (i.e. having trustworthy sources and content) and *clarity* (communicating in a clear, unambiguous manner) received almost the same importance ratings, reflecting their fundamental role in building audience trust. Measures related to understanding – such as an *enlightening* quality (being educational and illuminating), and *saliency* (emphasizing the core message) also ranked among the most important for Goal 1. Although *evoking emotions* (generating emotional response) was slightly less dominant than the top four, it still is the fifth on the list, indicating that emotions are also considered important for establishing trust (even if secondary to credibility and clarity) (see Figure 6.10).

Figure 6.10 *Likert-Scale Results Chart for Goal 1*



When looking at the measures, participants selected as "indispensable" for achieving Goal 1, a very similar picture emerges. The five measures most frequently selected as indispensable for building trust were *Clarity*, *Saliency*, *Credibility*, *Enlightening* and *Actionability* (in order of frequency). In fact, four of these – credibility, clarity, enlightening, and saliency – appeared in *both* the top-five importance ratings and the top-five indispensable lists for Goal 1, underscoring a strong consensus that these are absolutely critical criteria for trustworthy climate change visuals. Notably, credibility and clarity were not only rated as highly important by majority of the respondents but were also almost universally chosen as must-haves for this goal. This alignment suggests that participants see little distinction between a measure being "very important" and truly "indispensable" in the context of trust – at least for the highest-ranked factors: if a visualization is not clear and credible, it fundamentally cannot fulfill the trust-building goal (see Figure 6.11).

Figure 6.11 *Indispensable Measures Selected for Goal 1*



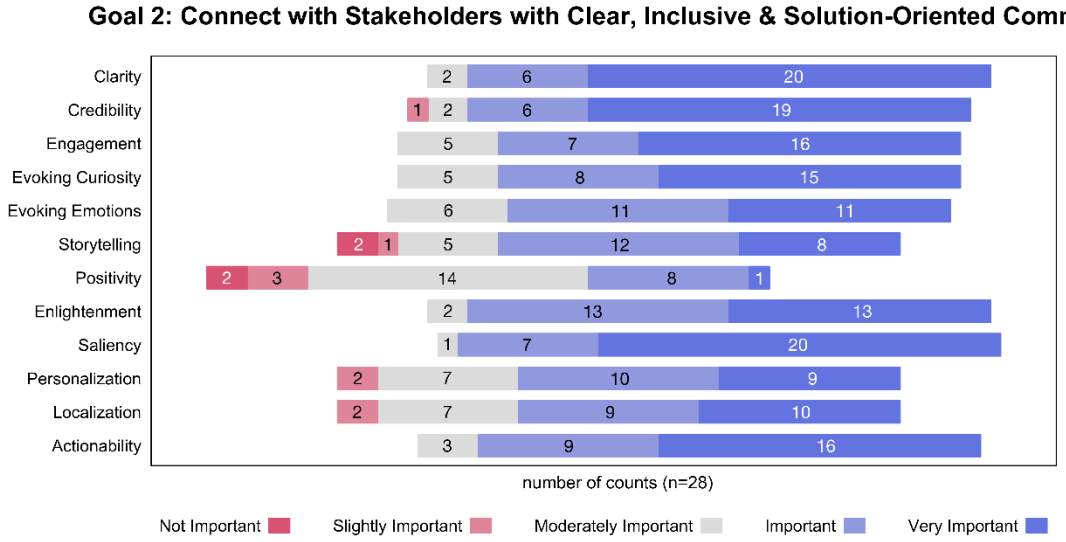
It is worth mentioning two measures that showed a slight difference between the two lists: *Evoking emotions* (14 votes in Likert-scale ratings) had high importance ratings and *Actionability* (13 votes in selecting the indispensable measures) was chosen as indispensable. Overall, however, the overlap between importance and indispensability for Goal 1 is high. This indicates a strong agreement that to foster trust in climate change visuals, certain core qualities (especially credibility of content and clarity of presentation) are non-negotiable. Minor differences hint that while generating emotions in design is valued alongside not forgetting about actionability, it cannot substitute for the clear communication of climate information when trust is the primary goal.

6.2.2 Measures for Goal 2: Clear, Inclusive, and Solution-Oriented Communication

For the second goal – connecting with stakeholders through clear, inclusive, and solution-oriented communication – participants' responses highlighted a somewhat different mix of top measures, reflecting the goal's emphasis on broad engagement and

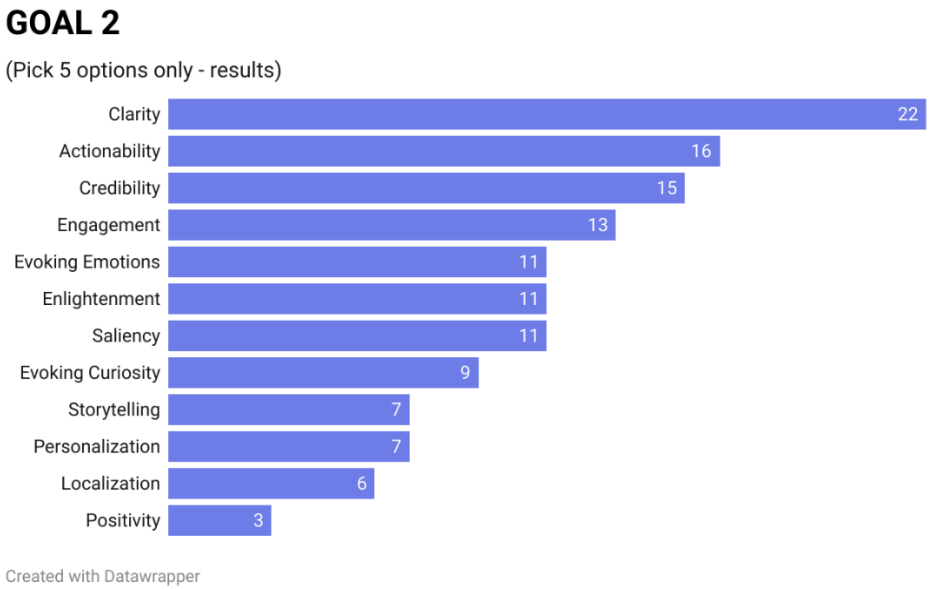
actionable information. The five measures with the highest importance ratings for Goal 2 were *clarity*, *saliency*, *credibility*, *engagement*, and *actionability*. *Clarity* again emerged as a leading criterion, reinforcing that a clear presentation is foundational to any effective communication. *Saliency*, emphasizing the core message, received an equally high rating, pairing closely with clarity and highlighting the critical aspect of clearly communicating the essential message. *Credibility* ranked third, slightly below the top two measures, indicating that trust continues to be a fundamental aspect of effective communication even if it is not the primary focus of this specific goal. *Engagement* was also rated as important in this context, aligning with the objective of actively engaging stakeholders—respondents recognized the necessity of capturing and maintaining audience attention to successfully convey solutions to diverse stakeholders. Adding to that *actionability,* defined as the capacity to encourage action on climate issues, was rated highly for Goal 2, emphasizing its alignment with the goal's solution-oriented approach. It highlights that participants value visuals capable of informing and empowering viewers to take action. Additionally, *positivity* received notably low scores for Goal 2, contrasting significantly with other measures. This surprising negative ranking of positivity suggests a nuanced aspect worthy of further investigation (see Figure 6.12).

Figure 6.12 *Likert-Scale Results Chart for Goal 2*



Looking at Figure 6.13, the indispensable measures for Goal 2, there is considerable overlap with the importance ratings, though with one notable difference. The five measures most frequently picked as indispensable for achieving clear, inclusive, solution-focused communication were *clarity*, *actionability*, *credibility*, *engagement* and *evoking emotions*. Four of these measures overlap directly with the top-rated important measures, showing strong agreement among participants. The consensus on *clarity* continues here – it was selected as the top essential for Goal 2, just as it was highly rated in importance. *Actionability* was another measure frequently selected as indispensable, consistent with its high importance rating – respondents clearly view driving action and offering solutions as a key outcome for this communication goal, and thus a feature a climate visualization must possess. Likewise, *credibility* ranked the third in the indispensable measures list for Goal 2. On the fourth rank, *engagement* was selected as a must-have measure, reinforcing that grabbing attention is not just nice-to-have but seen as a requisite for engaging broad audiences in climate issues (see Figure 6.13).

Figure 6.13 *Indispensable Measures Selected for Goal 2*



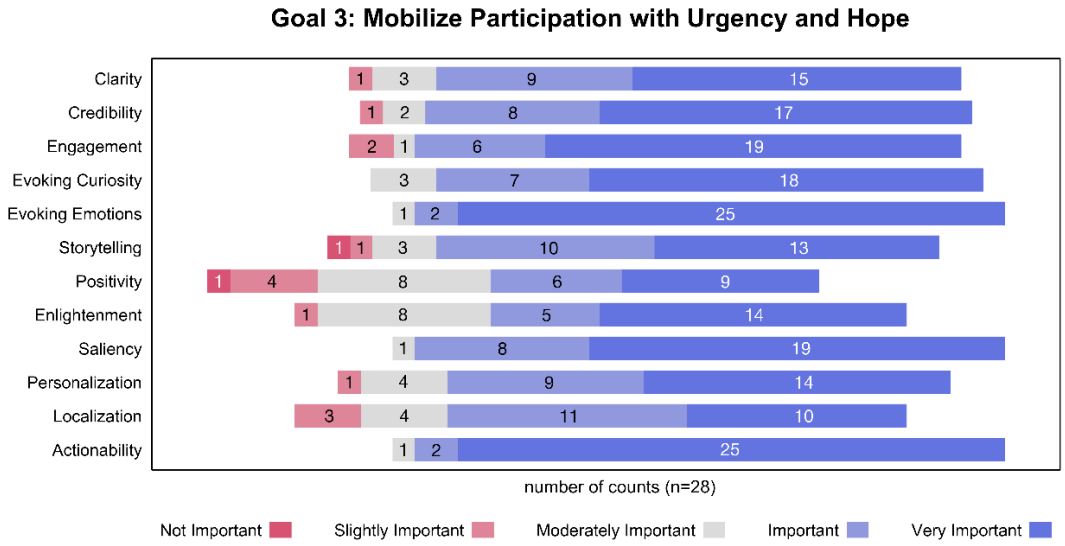
One point of divergence was the role of *saliency* and *evoking emotions* in this goal's context. Despite *saliency's* high importance rating on the Likert scale, it was notably absent from the top five indispensable measures for Goal 2. Conversely, *evoking emotions* was identified as indispensable, despite not ranking in the top five importance measures. This discrepancy suggests participants perceive emotional engagement as critically essential for inclusivity and stakeholder connection, maybe more so than highlighting the central message itself. *Saliency*, although important, may have been implicitly considered within clarity or viewed as less essential compared to direct emotional appeal for achieving inclusive, solution-oriented communication.

6.2.3 Measures for Goal 3: Encouraging Action with Urgency and Hope

For the third goal—motivating action on climate change while conveying urgency and hope—a distinct hierarchy of measures emerged, emphasizing emotional and action-oriented factors. According to the Likert-scale responses, the five measures rated most important for Goal 3 were *actionability*, *evoking emotions*, *engagement*, *saliency*, and

evoking curiosity. Among these, *actionability* received the highest importance, aligning clearly with the goal's focus on motivating immediate responses and tangible actions toward climate issues. *Evoking emotions* was also rated as important, underlining the participants' consensus on the need to engage audiences emotionally to inspire urgency and responses. *Engagement* continued to appear as a highly valued measure, reinforcing that capturing and maintaining audience attention remains crucial when the goal involves prompting immediate behavioral responses. *Saliency* was ranked highly as well, suggesting the experts view emphasizing core messages as essential for communicating urgency effectively. Interestingly, *evoking curiosity* was also among the top measures for Goal 3, highlighting participants' belief in the value of stimulating audience interest as a pathway toward deeper engagement and action (see Figure 6.14).

Figure 6.14 *Likert-Scale Results Chart for Goal*

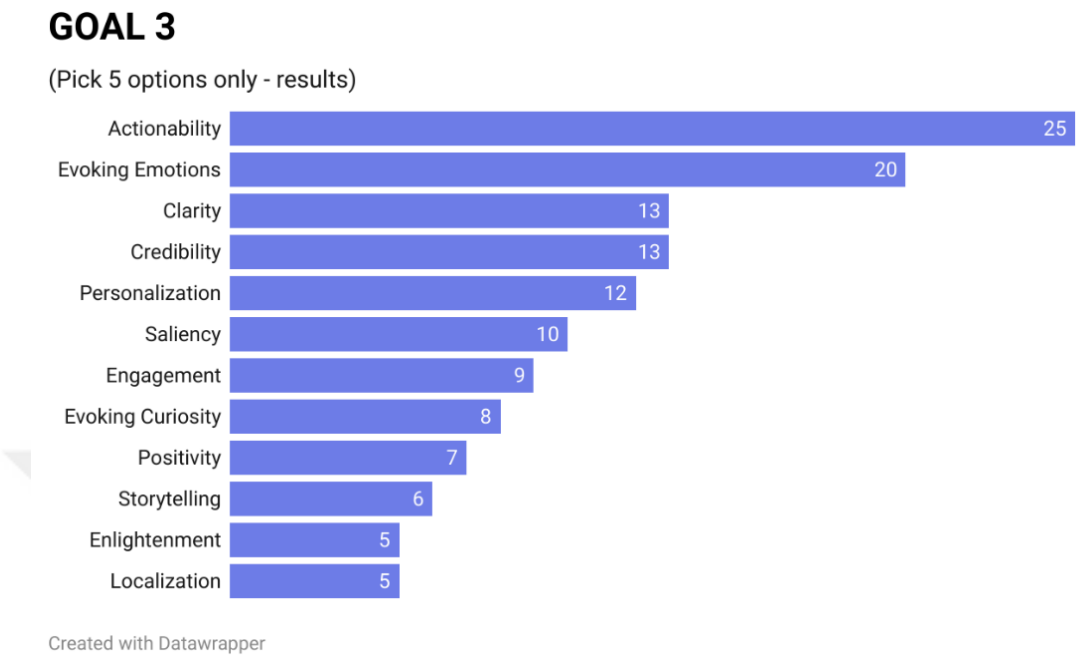


In contrast, *positivity* once again received notably low ratings for Goal 3, mirroring its similarly negative evaluation observed in Goal 2. This consistently low rating indicates participants' possible skepticism regarding overly optimistic messaging

in contexts requiring immediate and potentially uncomfortable actions. The repeated low scores may suggest that emphasizing urgency and seriousness may be perceived as incompatible with overly positive framing, pointing to a critical area for further research.

Turning to the indispensable measures identified for Goal 3 (Encouraging Action), the five measures selected as essential were *actionability*, *evoking emotions*, *clarity*, *credibility*, and *personalization*. As expected, *actionability* retained its top-rank as an indispensable measure, reinforcing its centrality in visuals aimed explicitly at driving immediate climate-related actions. *Evoking emotions* similarly remained essential, aligning with its critical importance rating and emphasizing the experts' belief in emotional resonance as key to action-oriented communication. Adding to that, *clarity* and *credibility* appeared among the indispensable measures, although they were not in the top five important ratings for this goal. This inclusion shows participants' view that clarity of communication and trustworthiness of information remain non-negotiable, even in emotionally charged contexts. Lastly, *personalization* was identified as indispensable, reflecting the respondents' perception that tailored visual content, relevant to individual contexts, significantly enhances the potential to motivate actionable responses (see Figure 6.15).

Figure 6.15 *Indispensable Measures Selected for Goal 3*



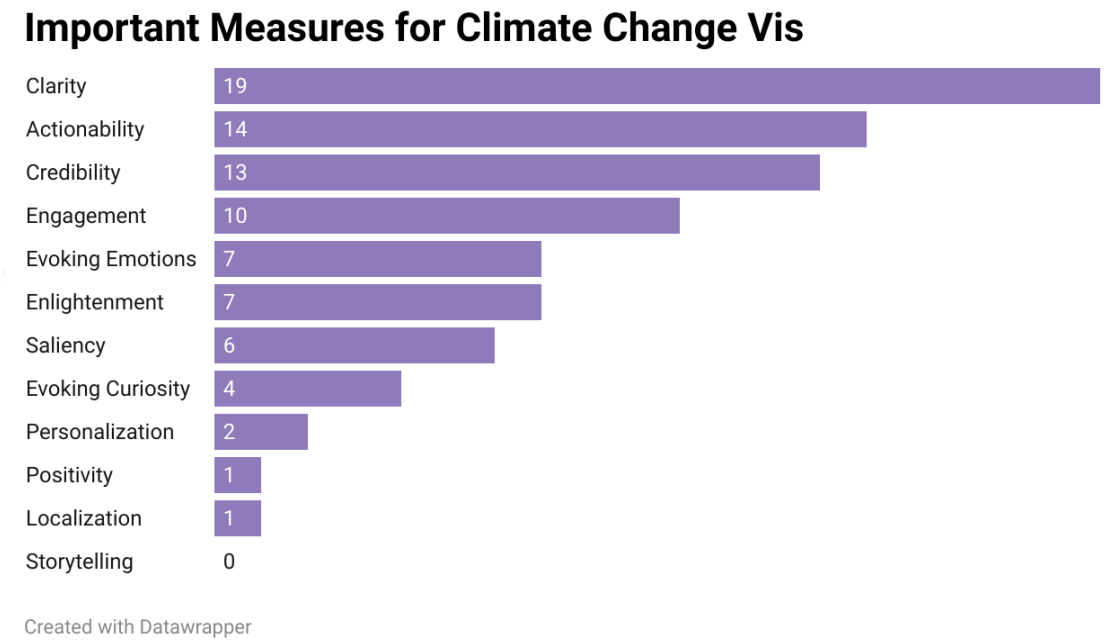
One interesting divergence is the absence of *saliency* and *evoking curiosity* from the indispensable measures list, despite their high ratings in the Likert-scale evaluation. While both measures were acknowledged as important for effectively communicating urgency, participants might have considered them implicitly addressed through clarity and personalization, or perceived them as valuable but not strictly essential compared to the indispensable qualities of credibility and direct emotional engagement. This nuanced prioritization highlights the careful balance experts maintain between core communicative qualities and those specifically align with the emotional and motivational demands of climate action messaging.

6.2.4 On the Overall Effectiveness of Measures

Participants were asked in a separate question to identify three indispensable measures for the overall effectiveness of climate change information visualizations. They selected *clarity*, *actionability* and *credibility* as the top 3 measures. *Engagement* and

evoking emotions followed as the fourth and fifth most important measures that are crucial for impactful visual communication (see Figure 6.16).

Figure 6.16 *Overall Ranking of Measures for Effective Climate Change Communication*



Notably, *clarity* was universally emphasized, underlining its fundamental importance in delivering accessible and easily interpretable information. *Actionability* ranked second as a significant measure, reflecting the necessity for visual content to not only inform but also inspire tangible actions. *Credibility* was also highlighted significantly, stressing that visualizations must be trustworthy and grounded in reliable sources to effectively communicate climate information.

Engagement and *evoking emotions* were similarly regarded as indispensable, highlighting the need for visualizations to actively involve the audience and emotionally resonate to enhance impact and memorability. In contrast, *positivity* and *localization* received minimal emphasis, getting only one vote each, while storytelling surprisingly received no votes at all. This distribution suggests participants prioritize clear, credible,

and emotionally engaging content over positivity, localized framing, or narrative-driven approaches.

The minimal votes for *positivity* and *localization* suggest that experts might view overly optimistic messaging or highly localized content as less universally effective or critical. The absence of votes for storytelling indicates that narrative methods, though popular in broader communication fields, are not considered essential in the specific context of climate change visualization effectiveness.

6.2.5 Cross-Goal Synthesis and Overall Critical Measures

The analysis of the survey results across the three distinct communication goals— building trust through reliable information, fostering clear and inclusive stakeholder communication, and encouraging action with urgency and hope— reveals both consistencies and notable differences in the prioritization of information visualization measures. Overall, the findings highlight a strong set of core measures essential across different goals, while also emphasizing the importance of context-specific nuances.

Primarily, *clarity* and *credibility* emerge as foundational measures, consistently identified as either highly important or indispensable across all three communication contexts. Their recurrent importance shows a fundamental consensus among experts that effective climate change visualizations must deliver clear, understandable information from credible sources. Without achieving these foundational aspects, other measures lose their significance, regardless of the specific communicative goal.

Additionally, measures like *actionability*, *engagement*, and *evoking emotions* also appear consistently, though their perceived importance varies depending on context. *Actionability* is particularly emphasized in contexts that explicitly aim to prompt behavioral responses (Goals 2 and 3), reinforcing the need for visualizations not only to

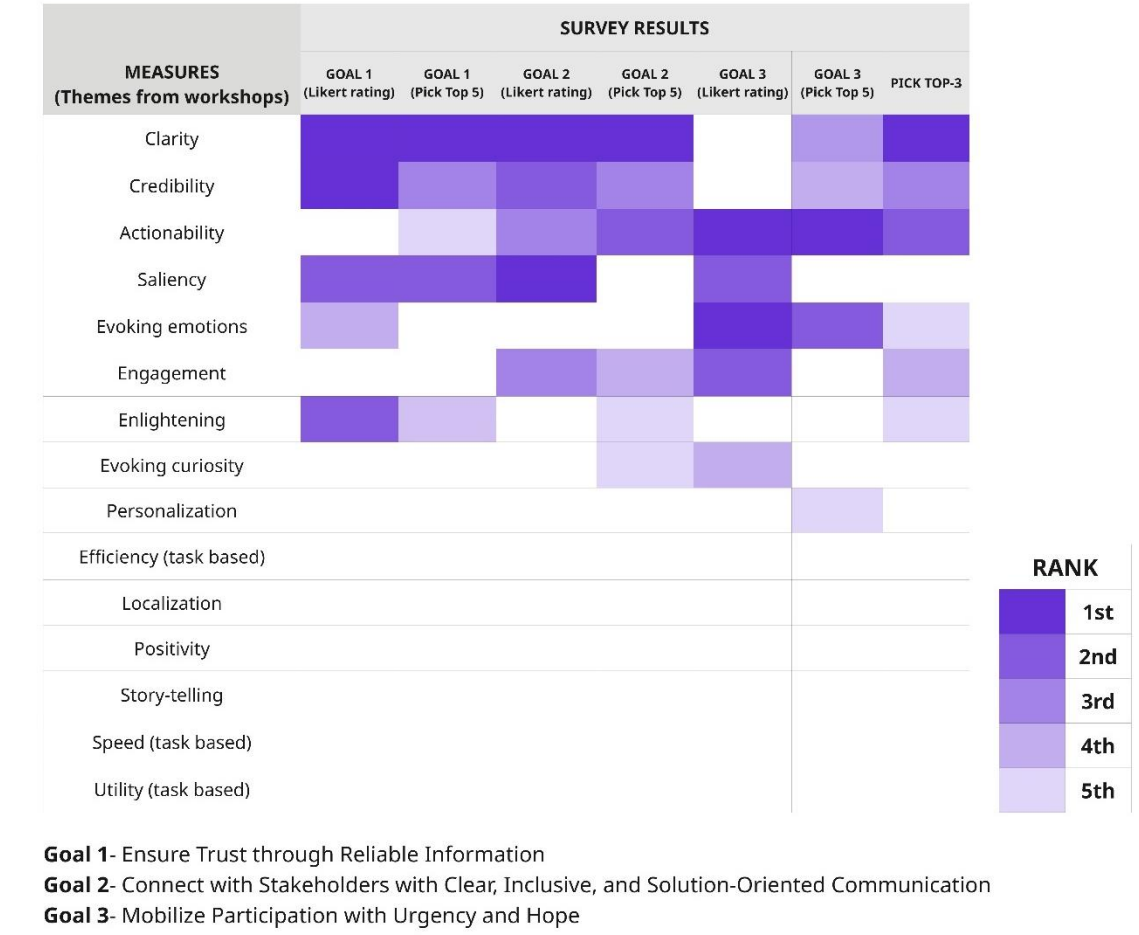
inform but also to empower action. Similarly, *engagement* is consistently valued for its role in capturing attention and sustaining audience interaction across goals, highlighting its function as a universal measure supporting effective communication.

However, the results also illuminate critical points of difference. For instance, the role of *positivity* was consistently ranked negatively in the survey, suggesting that participants perceive overly optimistic framing as potentially undermining urgency or credibility in certain contexts. Such findings indicate a sophisticated awareness among participants about the risks of over-emphasizing positive messages in urgent, action-oriented communications, representing a valuable area for further exploration.

Moreover, the varying prioritization of measures such as *saliency, evoking curiosity*, and *personalization* reveals context-specific distinctions. While *saliency* was highly rated in importance for all goals, its absence from the indispensable measures in Goals 2 and 3 implies participants may have viewed emphasizing the core message as implicitly embedded within other key measures such as clarity or credibility. This assumption also needs further exploration for verification. Similarly, the high ranking of *evoking curiosity* for motivating immediate actions, yet its exclusion from indispensable criteria, suggests that while intriguing the audience can enhance engagement, it is not seen as an absolute necessity when compared to emotional resonance or tailored messaging.

Figure 6.17 presents a detailed breakdown of how each measure was evaluated across the three communication goals using both Likert scale ratings and “top-5” prioritization. It visually underlines several key insights discussed in the analysis. Most notably, *clarity* and *credibility* emerge as the most consistently prioritized measures across all three goals, ranking among the top five selections in each case.

Figure 6.17 *Survey Results and Themes from the Workshops*



Goal 1- Ensure Trust through Reliable Information
Goal 2- Connect with Stakeholders with Clear, Inclusive, and Solution-Oriented Communication
Goal 3- Mobilize Participation with Urgency and Hope

The figure also highlights *actionability* as a measure gaining increasing importance for Goals 2 and 3. Although not always the top-ranked in Likert averages, *actionability* was frequently selected among the indispensable top five, emphasizing its critical role in motivating user response. In contrast, *positivity* stands out in the figure for its relatively low rankings across all three goals, aligning with textual findings that suggest cautious optimism is preferred over overly positive messaging. Additionally, measures like *evoking emotions*, *personalization*, and *evoking curiosity* exhibit a more varied pattern across goals—illustrating their context-specific relevance. Their placement on the chart confirms that while they are seen as valuable, their indispensability is

conditional, reflecting the complexity of balancing universal principles with tailored strategies. Overall, the figure substantiates the framework's core claim: that no single hierarchy of measures suffices for all communication goals. Instead, effective visualization design must flexibly integrate foundational and goal-specific criteria depending on context.

Through this nuanced display of measures, the conceptual framework developed through this study shows that no single measure or uniform hierarchy of criteria suffices across varied communication objectives. Instead, the results validate the framework's assertion that effective climate change visualizations must carefully balance foundational measures—*clarity*, *credibility*—with additional context-driven criteria—*actionability*, *evoking emotions*, *personalization*—to fulfill specific communication objectives effectively. In conclusion, the empirical insights from this survey indicate that effective information visualization for climate change communication involves not only adhering to universally valued principles but also strategically selecting and balancing additional measures to align with clearly defined communication goals. The findings suggest a dynamic, context-sensitive approach, enabling designers and researchers to craft visualizations that resonate authentically and persuasively with diverse audiences, ultimately advancing both theoretical understanding and practical effectiveness in climate change communication.

7. CONCLUSION

This dissertation set out to investigate the measures of effective information visualization in the climate change context. By responding to three research questions, this study has identified and analyzed the prominent measures for visualizing climate data, with an emphasis on their interrelationships and contextual relevance. The summary of how these questions were answered, findings, contributions, and limitations of the study are highlighted below.

The study identified an expanded list of measures by conducting a literature review and exploratory interviews. Some examples include *clarity*, *credibility*, *engagement*, *actionability*, *positivity*, and *saliency*, among other categories of perceptual, task-oriented, affective, and goal-oriented measures. These give a wide insight into what constitutes the qualities of an effective information visualization (answer for RQ1).

Following the literature review, a preliminary study with three interviews and five workshops were conducted with communication design academics, design professionals, sustainability experts and experts from NGOs. As the findings of these research, *actionability*, *clarity, credibility, engagement, enlightening*, *evoking curiosity*, *evoking emotions*, *localization*, *personalization, positivity, saliency* and *storytelling* as specific measures in information visualizations about the climate crisis (answer for RQ2).

The *actionability* measure focuses on the ability to trigger and inspire the audience to execute personal and public-level actions based on the information presented. This is achieved by using attractive images, clear designs, and personified content. *Clarity* ensures communications are easily understood through the use of simple and terminology-free communication. *Credibility* indicates that the use of verifiable sources of data as well as professional visual display must be observed to create trust. *Engagement*

can be elevated with imaginative graphics, illustrations, and other elements attracting and sustaining attention. To bring the audience closer to awareness of the problem of climate, educational methods are made available by the *enlightening* measure for audiences of diverse levels of comprehension. The approaches utilize clear explanations and information that is layered. Through the use of unexpected hooks, catching graphics, and new design features *evoking curiosity* measure aid in increasing engagement. *Evoking emotions* plays a critical role in expressing the significance of the message and in creating connection through feelings of hope, urgency, or even fear. *Localization* is the process by which the material is made relevant to the immediate context of the audience, bridging the gap between distant global concerns and local experiences. By applying the *personalization* measure, the issue becomes more relatable to the audience since it is connected to their daily life. It enables the development of a feeling of belonging within a wider and more inclusive public narrative. To counter eco-anxiety and to promote action, maintaining *positivity* helps preserve motivation and involvement while striking a balance between hope and urgency. *Saliency*, which may be achieved through the use of visual tactics such as strong lettering and concentrated color use, ensures that the most important information is brought to the fore. The *storytelling* measure contributes to the development of the narrative element by putting facts into interesting stories, enhancing knowledge and emotional bond.

After pinpointing these measures, a conceptual framework that evaluates these measures with three goals of climate change communication was presented. The framework aligns identified visualization measures with specific communication objectives, highlighting their interrelationships and contextual dependencies. The first goal, building trust through reliable information, primarily involves *credibility*, *clarity*,

saliency and *enlightening* measures, which reinforce audience trust and facilitate accurate interpretation of data. The second goal, facilitating clear, inclusive, and solution-oriented communication, particularly engages measures such as *clarity*, *credibility*, *saliency* and *actionability*. These measures collectively ensure that information is accessible, comprehensible, relevant, and relatable to diverse audiences. Lastly, the third goal, motivating action with a balanced sense of urgency and hope, strongly correlates with *actionability*, *evoking emotions*, *engagement*, and *saliency*. Together, these measures enhance motivation, foster emotional engagement, and encourage proactive behavioral responses. Overall, the top three measures effective for climate change communication are *clarity*, *credibility* and *actionability* (answer for RQ3).

Limitations of the study: The workshops, though diverse, were small in size and geographic representation. Broader participation might provide more generalized insights. Adding to that the collection of information visualizations were drawn from social media and published between 2019–2023. A wider set of research materials may exclude longer-term trends in climate communication. Moreover, while the study took lay audiences as the target for information visualization designs, it did not extensively cover measures for targeting expert or semi-expert users. The application of the framework in real-world campaigns or designs was not tested; thus, its practical effectiveness remains open for future research.

Future research directions: Future studies may explore the application of the framework in real-life campaigns. The focus can be expanded to diverse audiences from different localities or with different knowledge domains. Similar frameworks can also be created for other contexts such as economics, finance, education and health, in which information visualizations play a significant role.

To sum up, this dissertation targeted the very urgent and escalating climate crisis by providing a structured approach toward finding out the measures of effective information visualizations. This helps in connecting measures to goals and contextual needs, filling the gap between scientific data and public comprehension via effective information visualizations. Hopefully, carefully designed information visualization will aid the lay audiences be more informed, connected and motivated against the climate crisis.

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APPENDICES

APPENDIX A. FIRST LEVEL CODES, SECOND LEVEL CODES AND THEMES FROM PRELIMINARY STUDY

The following figures show the first level codes, second level codes and themes from the preliminary study.

Figure A.1 *Design Elements First and Second Level Codes*

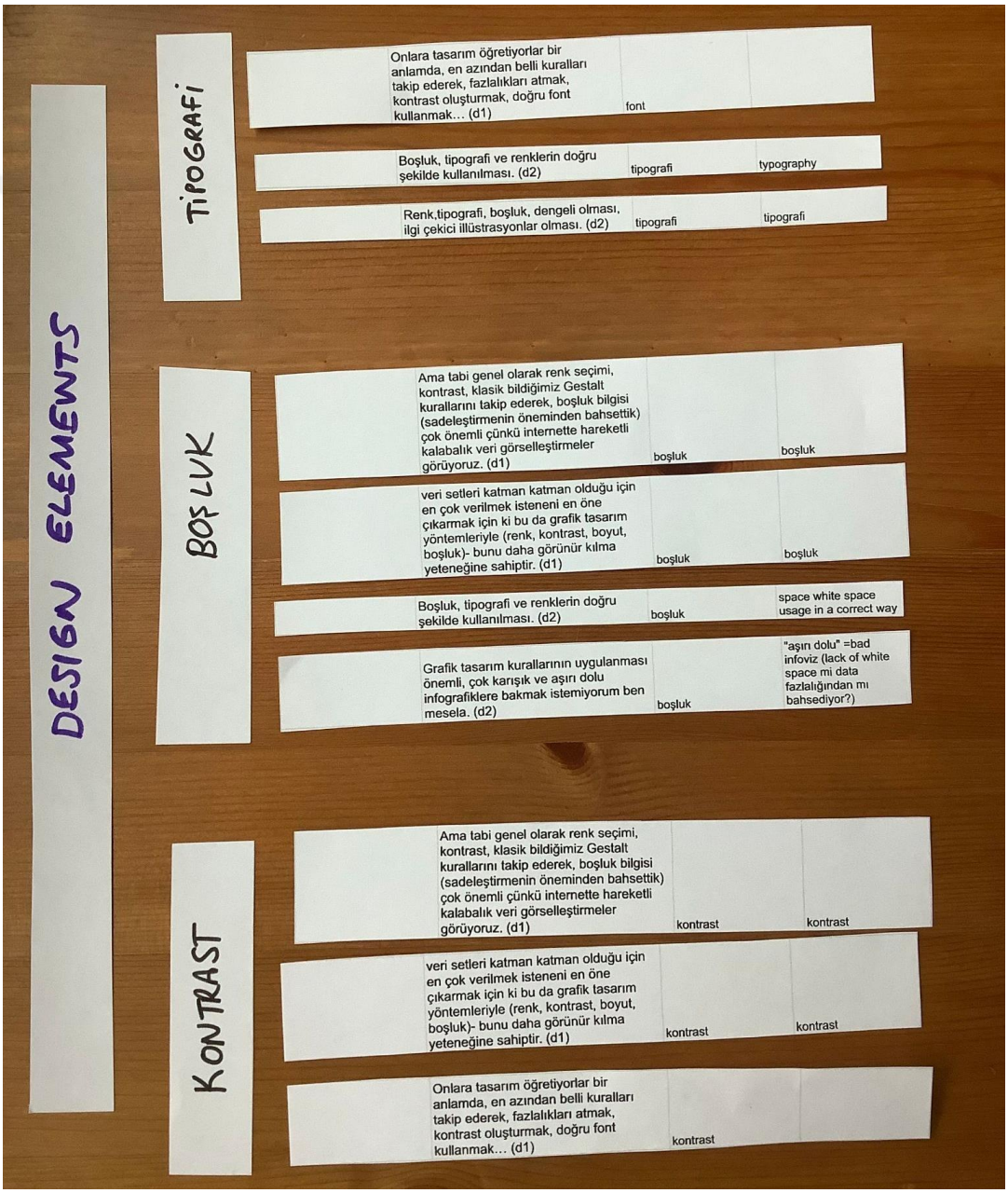


Figure A.2 *Design Elements First and Second Level Codes Continued*

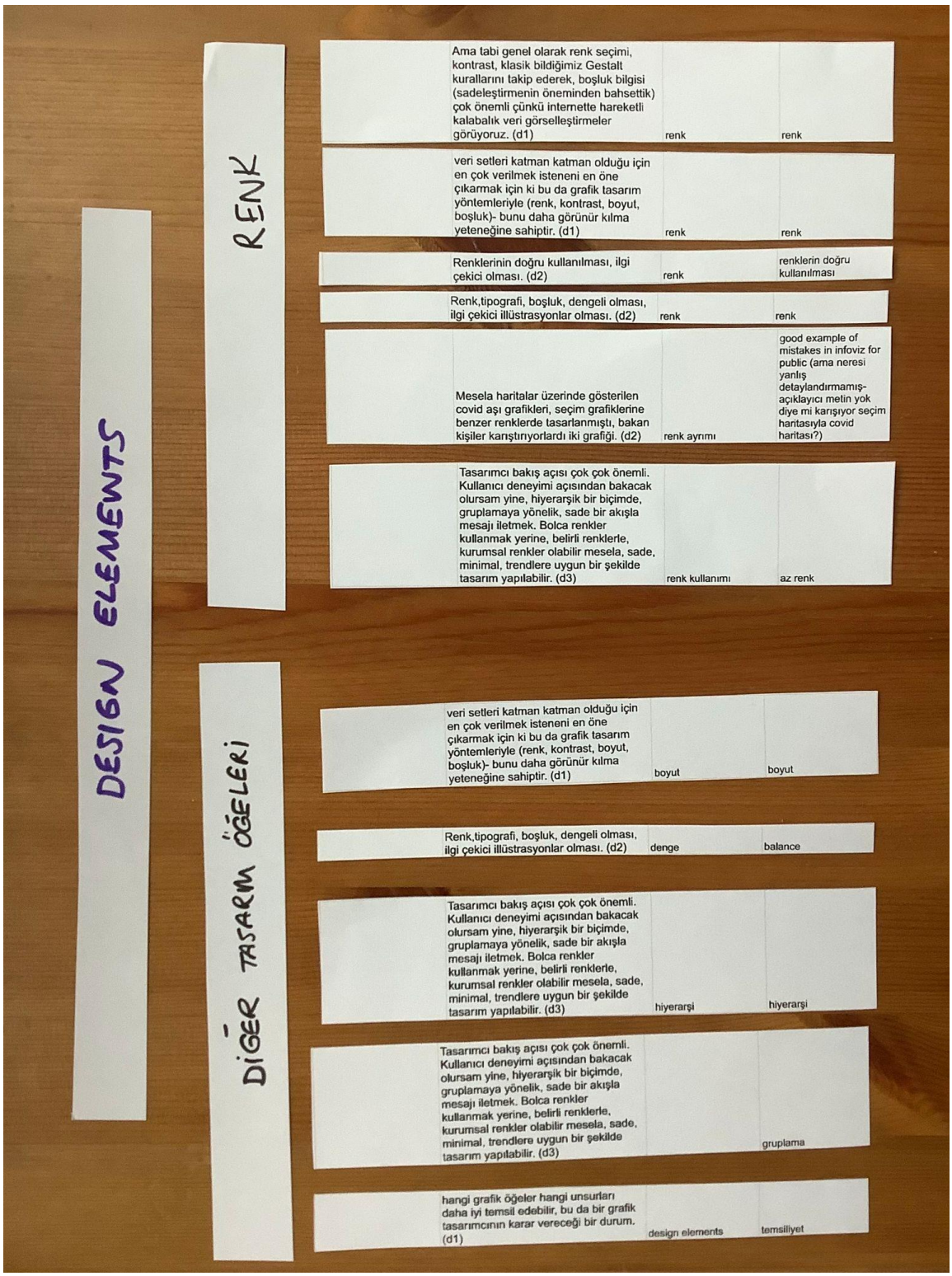


Figure A.3 *Design Principles First and Second Level Codes*

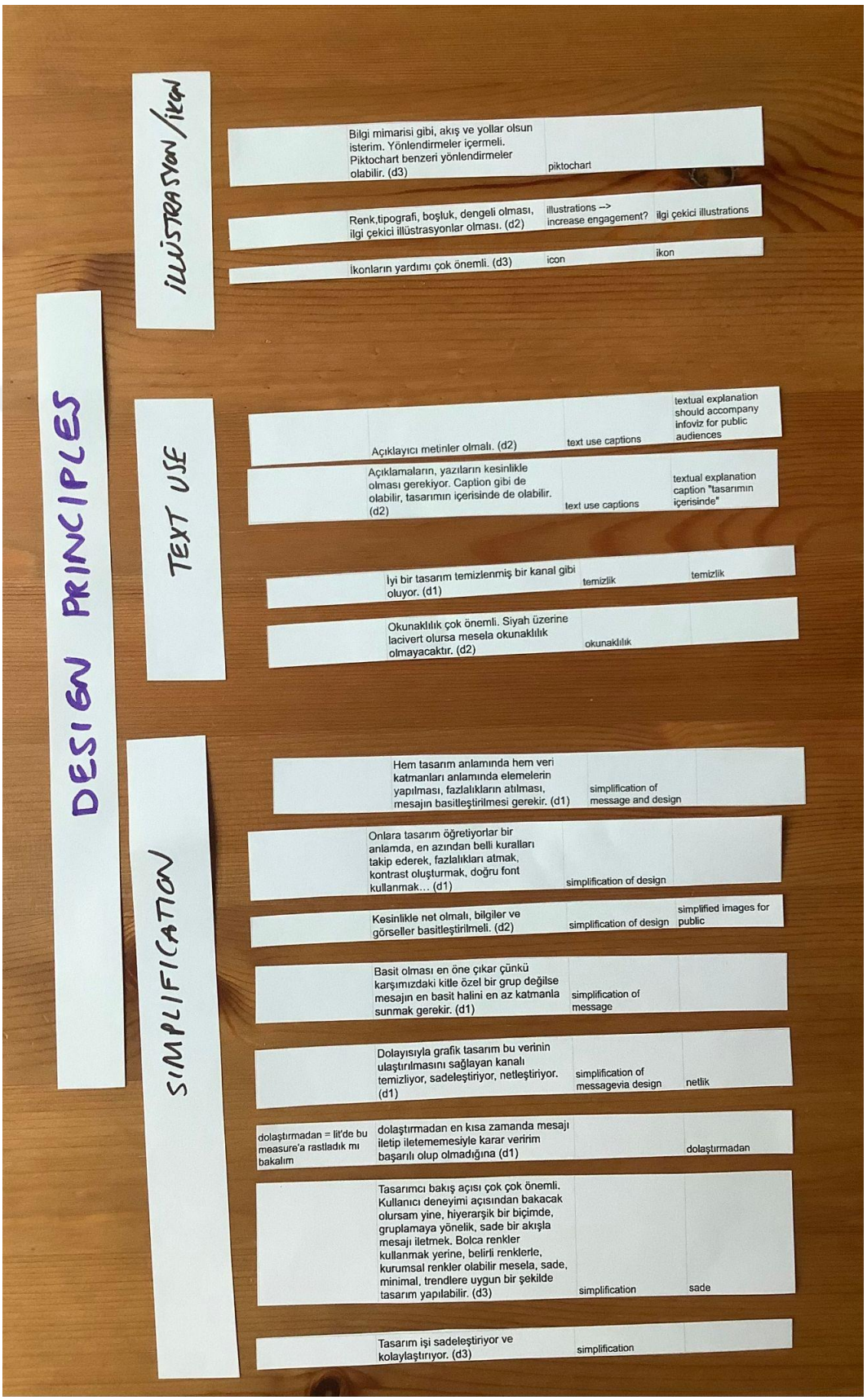


Figure A.4 *Measures First and Second Level Codes*

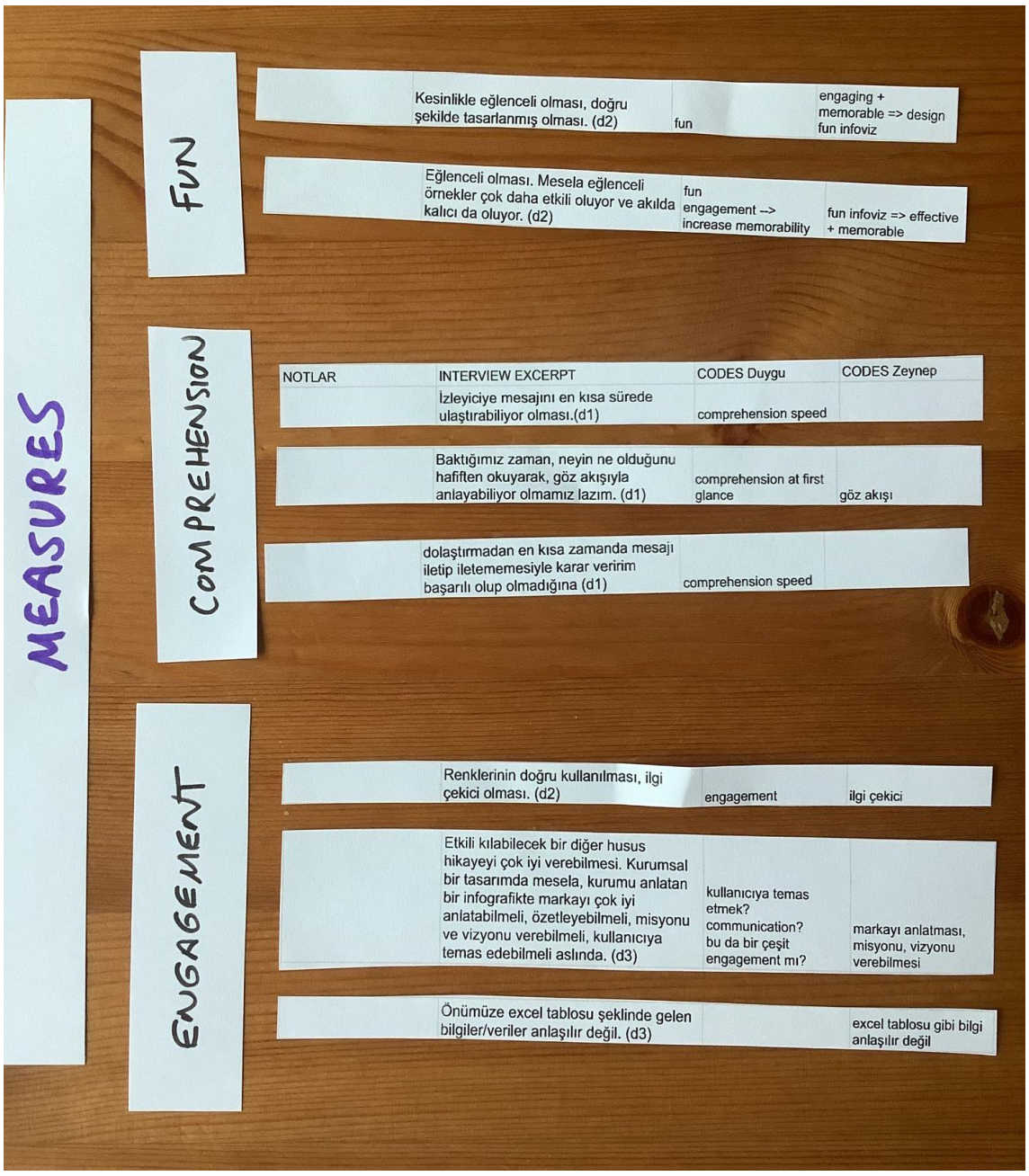


Figure A.5 *Measures First and Second Level Codes Continued*

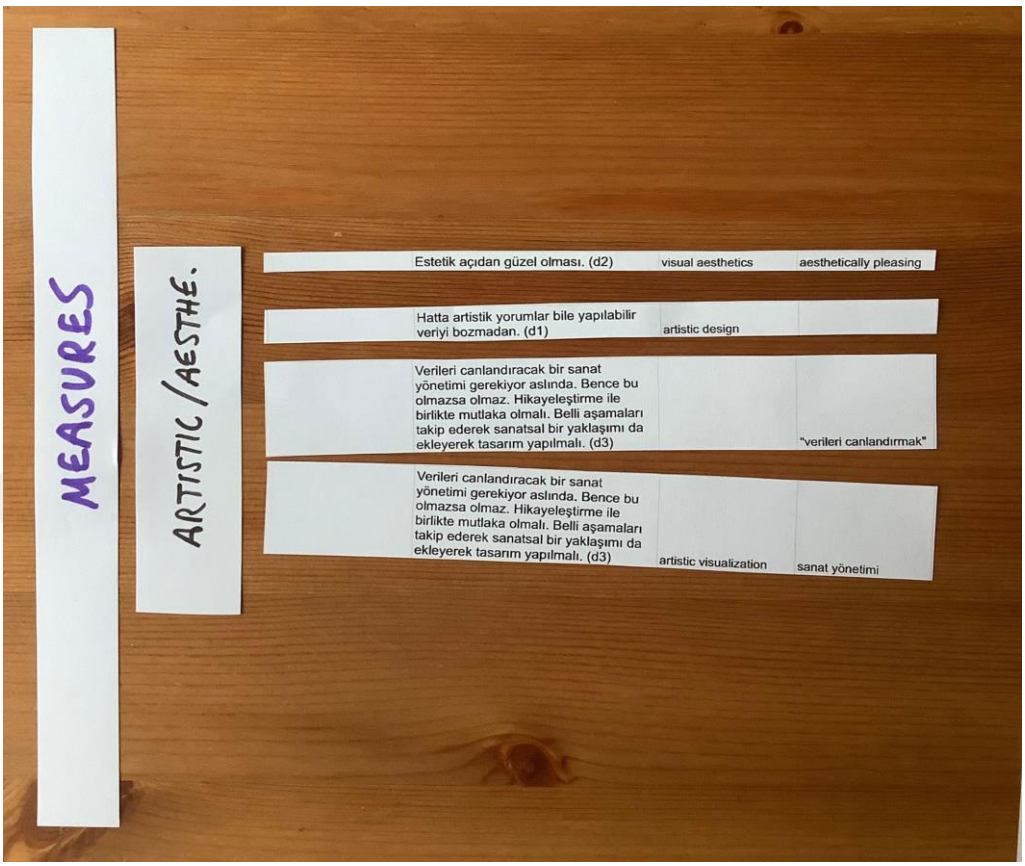


Figure A.6 *Design Language and Narrative First and Second Level Codes*

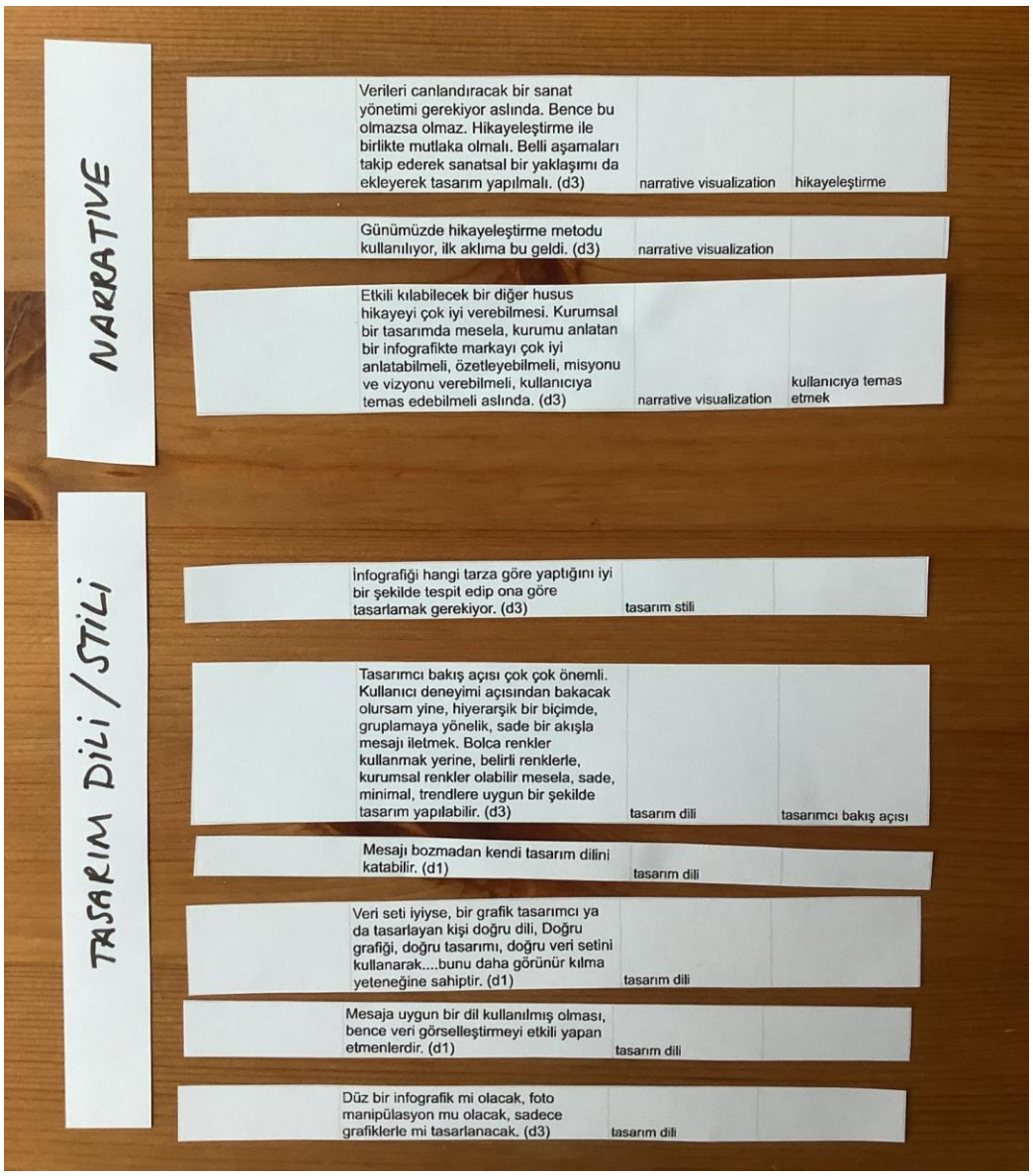


Figure A.7 *Design Decision and Aim First and Second Level Codes*

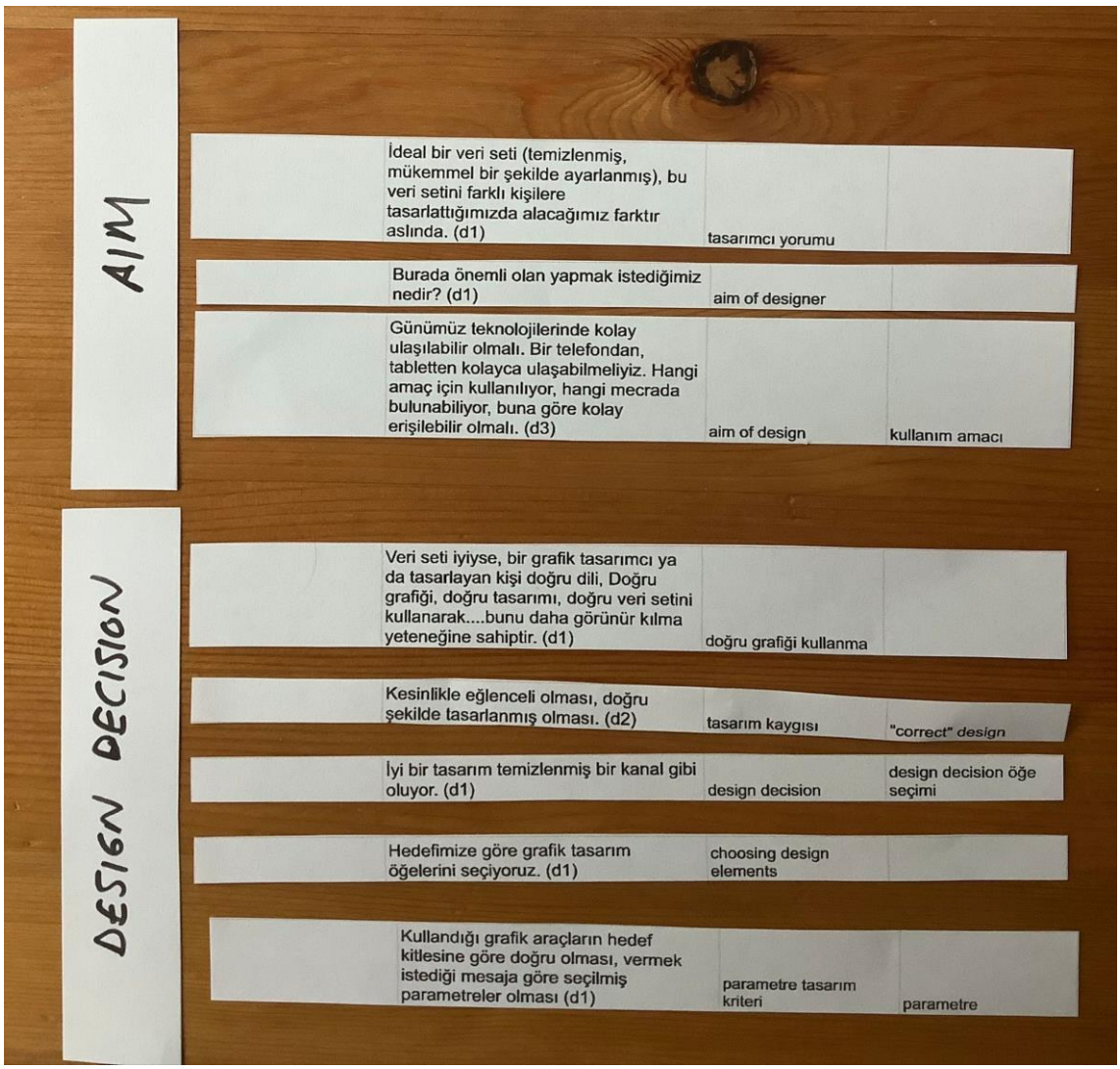


Figure A.8 *Data Layers, Systematic and Design Rules First and Second Level Codes*

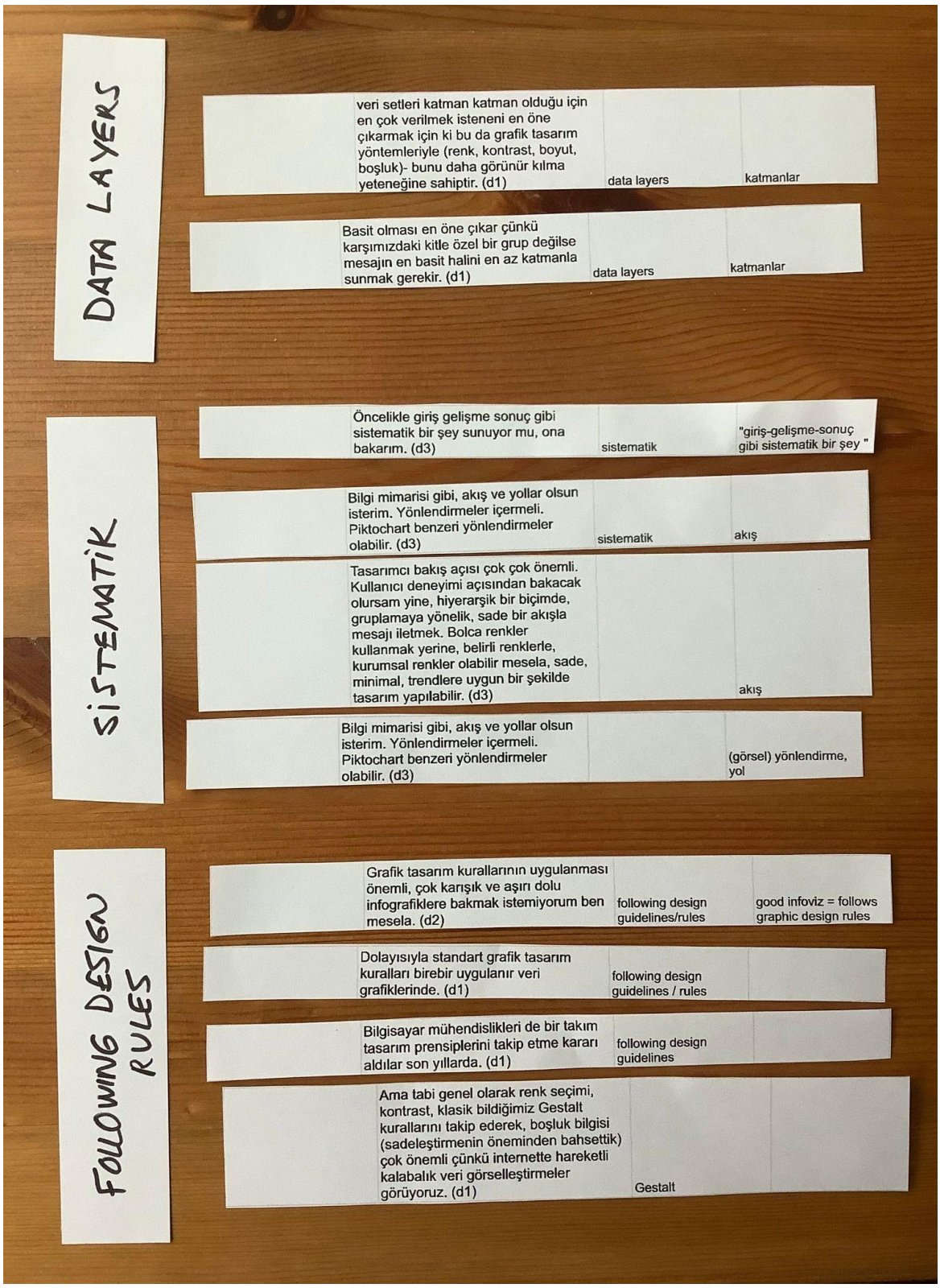
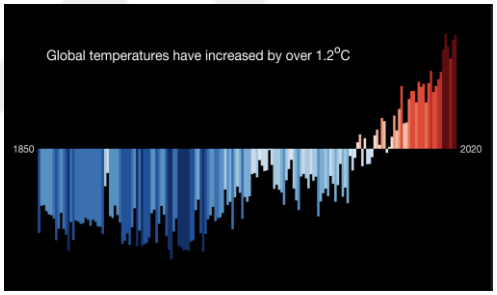


Figure A.9 *First Information Visualization Presented in Preliminary Study*



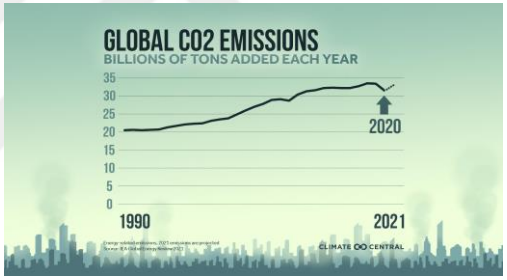
Source: Ed Hawkins, 2020, Retrieved from https://www.science.smith.edu/climatelit/warming-stripes/.

Table A.1 *Participant Ratings and Comments for First Information Visualization*

INFO VIS Özellikleri (NO:4)	**1**	**2**	**3**	**4**	**5**	**Katılımcı yorumları d1**	**Katılımcı yorumları d2**	**Katılımcı yorumları d3**
Memorability - akılda kalıcılık		d2	d3	d1		Anlayabilirsek akılda kalıcılığı yüksek		Daha net olabilirdi, sanki bir mühendisin elinden çıkmış gibi bir grafik
Comprehension-kavranabilirlik (anlaşılabilirlik)	d1	d3		d2		Veri eksikliği var. Her bir bar bir yılı mı temsil ediyor? Artışı görebiliyoruz ama tek tek veriyi görmüyoruz.		Uzaktan bakıp, gözümü kıstığımda sadece kırmızı ve mavi görüyorum. Aslında aradaki detaylar da önemli
Accuracy - kesinlik	d1, d2		d3			En yükseğe çıkan barlar hangi rakama kadar çıkıyor, barlar arasındaki fark ne kadar? Çok eksik bilgi var.	1850-2020 arasında bir yıl seçip oradaki sıcaklık verisini görmek istersem kaç olduğunu göremiyorum.	Detaylar eksik gibi
Efficiency - verimlilik	d3		d1, d2			Veriler tam ise eğer kullanılabilir bir grafik. Tasarım anlamında		

						seçilebilir. Renk kullanımı da soğuk sıcak olarak bu anlamda verimli.		
Utility - yararlılık	d3		d1, d2			Bakan kişinin ön bilgisi varsa yarar sağlayabilir ama benim gibi ön bilgisi olmayan bir kişi yarar sağlayamaz.		Isı haritasını andırıyor, borsa grafikleri bile daha ayrıntılı
Clarity - netlik		d1, d3	d2					Sağ, tarafta, aşağı ve yukarı doğru derecelendirmeyi görüyorum. Az çok bir şeyler anlıyor gibiyim
Speed - anlaşılma hızı	d1, d3		d3	d2			Genel olarak anlaşılıyor ancak detaylar yok	Ilk baktığımda ben buradan bir yükseliş anlıyorum.
Soundness - doğruluk	d2, d3					Veriyi görmeden doğruluğunu bilemiyorum. Üst alt limitleri görsek barların orantılarına da bakabilirdik. Çok özel bir gruba yapılmış bir grafik gibi duruyor. Bildiğiniz veriler içinde böyle yükselmiş demek için gibi.		Dereceleri göremiyorum. Belirsiz görünüyor.
Engagement - ilgi çekicilik	d2, d3		d1					Anlaşılır olmadığı için bakma hissi uyandırmıyor.
Enjoyment - eğlenceli	d1, d2, d3							
Attractiveness - estetik-çekici olması	d2, d3	d1				Tasarım kaygısı var. Daha iyi olabilir ama renkler kullanılmış, renk ayrımı yapılmış verilerle, arka plan siyah kullanılarak veri görselleştirme ön plana çıkarılmış. Tipografi orantılı gibi.	Çok koyu renkli bir arka planı var. Bu aslında estetik olarak kötü duruyor. İç karartıcı	

Figure A.10 *Second Information Visualization Presented in Preliminary Study*



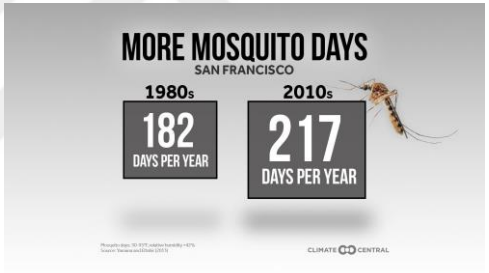
Source: Climate Central, 2021, https://www.climatecentral.org/climate-matters/covid-19-and-climate-change.

Table A.2 *Participant Ratings and Comments for Second Information Visualization*

INFO VIS Özellikleri (NO:7)	**1**	**2**	**3**	**4**	**5**	**Katılımcı yorumları d1**	**Katılımcı yorumları d2**	**Katılımcı yorumları d3**
Memorability - akılda kalıcılık				d1, d3	d2			Diğer örneğin tam zıttı gibi. Daha yüksek puanlar alacak gibi. Arka plan etkili.
Comprehension-kavranabilirlik (anlaşılabilirlik)				d3	d1, d2	Alttaki metin kaynağı belirtmiş bu da iyi bir unsur, gerekli bir unsur infografik için.	Her şey çok net.	Burada gayet net.
Accuracy - kesinlik				d1	d2, d3	2020 noktasında rakamsal veri tam olarak kaç göremiyoruz.		
Efficiency - verimlilik				d1,d 3	d2			Çok çok verimli. Sadece biraz daha minimalleştirelebilir.
Utility - yararlılık				d1	d2, d3	Büyük ihtimalle genel bir bilgi vermeye çalışıyor, bunu göstermekte başarılı.		

Clarity - netlik				d1	d2, d3			
Speed - anlaşılma hızı				d3	d1, d2			Burada birazcık gözü yoruyor aslında. Biraz daha toparlanabilir.
Soundness - doğruluk			d1		d2,d3	Kaynak veriyor olması verdiği verinin arkasında durduğunu gösteriyor. Veri grafiğini kritize etme davranışına alışkın olduğum için 3 puan veriyorum ama başka bir kişi daha yüksek puan verebilir.		Kaynakça verilmiş bize. İnfografikte kaynaklar çok önemli.
Engagement - ilgi çekicilik			d1	d3	d2	Bir önceki örnekten çok daha ilgi çekici. Geliştirebilecek tarafları var. 3-4 puan arasındayım.	Arka planın açık renk olması, ev görsellerinin kullanılması	Renklerden kaynaklı olarak çok ilgi çekici diyemem.
Enjoyment - eğlenceli		d3	d1		d2		Bir öncekine göre çok daha iyi bir tasarım	
Attractiveness - estetik-çekici olması			d3	d1	d2	İtici değil, önceki örnekten çok daha iyi. Bir tasarımcı tarafından tasarlanmış gibi görünüyor. Fontlar çeşitlendirilmiş, renk ayrımları yapılmış. Font hizalanmaları doğru, biraz kontrast düşük. Özellikle arkada kullanılan şehir ve karbondioksit görselleri biraz düşünülmesi gereken şeyler. İlgi çekici aslında 3,5-4 puan.	Tipografisi de iyi	Fontlar vs. günümüzü yansıtıyor, modern

Figure A.11 *Third Information Visualization Presented in Preliminary Study*



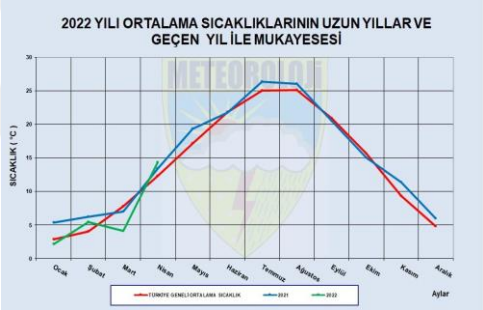
Source: Climate Central, July 29, 2020, Retrieved from https://www.climatecentral.org/climate-matters/more-mosquito-days.

Table A.3 *Participant Ratings and Comments for Third Information Visualization*

INFO VIS Özellikleri (NO:12)	**1**	**2**	**3**	**4**	**5**	**Katılımcı yorumları d1**	**Katılımcı yorumları d2**	**Katılımcı yorumları d3**
Memorability - akılda kalıcılık				d1	d2, d3	Akılda kalıcı ama pozitif bir akılda kalıcılık değil.		Afiş niteliğine gönderme yapıyor. Sivri kasıtlı olarak kullanılmış. Başlıktan sonra hatta başlıktan önce direkt sivriye odaklanıyorum.
Comprehension-kavranabilirlik (anlaşılabilirlik)				d1	d2, d3	Boyut kullanılmış rakamsal farkı göstermek için. Dikdörtgenlerin boyutuyla gösterilmiş, ama boyutu algılamak daha zor, başlıkla desteklemiş bu artışı.		Çok güzel fokuslanabiliyorsunuz.
Accuracy - kesinlik	d1				d2, d3	Kıyaslamak mümkün değil, tek bir bilgi var. Arada bir fark olduğunu göstermiş ama oransal kesinliği görmek mümkün değil.		Kaynak gösteriyor. Çok güzel toparlamışlar.
Efficiency - verimlilik	d1				d2,	Bir artış olduğunu göstermiş ama		

					d3	eski tarihsel bilgiler olmadığı için bu grafik sürekli artıyor mu yoksa iniş çıkışlı zigzag olarak mı gidiyor bilemiyoruz.		
Utility - yararlılık	d1				d2, d3	Geçmişi göremediğimiz için düşük. Çok az veri var, geneli göremiyoruz. Genel kitleye tasarım yaparken veriyi basitleştirelim demiştik ama bu çok fazla basitleştirilmiş ve manipüle etme yöntemi gibi duruyor.		Anlaşılır ve yararlı olduğunu düşünüyorum.
Clarity - netlik			d1		d2, d3	Çok az veri olduğu için net. Tek parametreye göre net.		
Speed - anlaşılma hızı			d1		d2, d3			Renkler vs. çok iyi kullanılmış.
Soundness - doğruluk		d1			d2, d3	Grafikte niye nemlilik yok, aşağıda böyle bir açıklama vermiş ama grafikte bunu göremiyorum. Açıklama kafamı karıştırıyor.	Altta kaynak da verilmiş.	
Engagement - ilgi çekicilik			d1, d2		d3	Kullanılan sivrisinek görseli sebebiyle ilgili çekici.		
Enjoyment - eğlenceli	d1		d2	d3				Sivri işi bozuyor :) çok sade, biraz hikayeleştirme de var.
Attractiveness - estetik-çekici olması		d1		d2	d3	Çok da düşünülmeden yapılmış bir tasarıma benziyor ama bir önceki tasarımdaki benzer kaygılardan söz etmek mümkün.	Gri yerine kırmızı gibi "kan-sivrisinek" ilişkisini gösterecek bir renk tercih edilebilirdi.	

Figure A.12 *Fourth Information Visualization Presented in Preliminary Study*



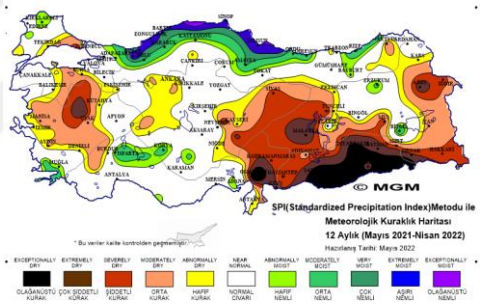
Source: Turkish State Meteorological Service, 2022, Retrieved from https://www.mgm.gov.tr/files/iklim/yillikiklim/2022-iklim-raporu.pdf.

Table A.4 *Participant Ratings and Comments for Fourth Information Visualization*

INFO VIS Özellikleri (NO:18)	**1**	**2**	**3**	**4**	**5**	**Katılımcı yorumları d1**	**Katılımcı yorumları d2**	**Katılımcı yorumları d3**
Memorability - akılda kalıcılık	d2		d3	d1				Bir dağ çiziyor aslında.
Comprehension-kavranabilirlik (anlaşılabilirlik)		d2	d3	d1		Doğru bir grafik kullanılmış, ne demek istediğini gösteriyor.	Çizgiler birbirine girmiş hiç anlaşılmıyor. Arkadaki kareler ve logo kafa karıştırıyor. Hangisine bakacağıma karar veremiyorum.	Alttaki lejanda göre geneli veriyor, 2021 ve 2022'yi veriyor.
Accuracy - kesinlik		d2, d3		d1		Daha kesin bilgi verilebilir di ama gayet vermek istediği de detaylandırmış.		Görsellik açısından zayıf, veri açısında bir kaynağı yok.
Efficiency - verimlilik		d2	d3	d1				
Utility - yararlılık		d2	d3	d1				Sol taraftaki dereceler de görünüyor. Yararlanılabilir.

Clarity - netlik	d2	d3	d1			3-4 puan arası. Anlamak için biraz zaman harcadım.		Yeterli bulmadım
Speed - anlaşılma hızı	d2		d1, d3			Biraz zamanımı aldı, tüm parametreleri aynı şekilde gösterdiği için, tasarım anlamında geliştirilebilecek bir tarafı var, o yüzden anlaşılma hızı düşüyor.		
Soundness - doğruluk		d3	d2	d1		Arkada kurum logosu verilmiş, o yüzden bir doğruluk hissi var. Kıyaslayacağım veri bende değil ancak standart olarak doğruymuş gibi davranılabilir.		Meteoroloji logosu var ama yine de yeterli değil.
Engagement - ilgi çekicilik	d2, d3		d1			Kişisel bir konu ilgi çekicilik. Sonucu anladıktan sonra ilgimi çekti ancak ilk defa gördüğümde bu grafiğe bakmazdım.		Arkadaki logoyu çok büyük koymaları hiç olmamış. Kimse bakmaz buna, lejand filan hiç belirgin değil. Herşey karmakarışık.
Enjoyment - eğlenceli	d1, d2, d3							
Attractiveness - estetik-çekici olması	d1, d2, d3						Çok kötü bir tasarım. O kadar kötü ki aklımdan çıkaramıyorum :) Gözlerimi acıtıyor.	Çok çok eski bir tasarım stili.

Figure A.13 *Fifth Information Visualization Presented in Preliminary Study*



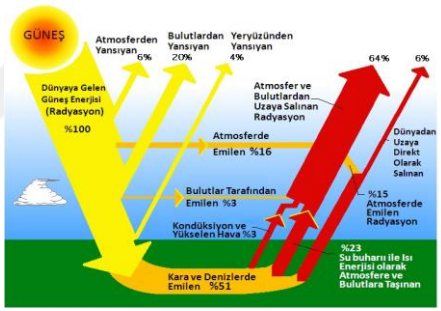
Source: Turkish State Meteorological Service, 2022, Retrieved from https://www.temizmekan.com/iklim-degisikligi-ve-kuraklik/.

Table A.5 *Participant Ratings and Comments for Fifth Information Visualization*

INFO VIS Özellikleri (NO:19)	1	2	3	4	5	Katılımcı yorumları d1	Katılımcı yorumları d2	Katılımcı yorumları d3
Memorability - akılda kalıcılık	d2, d3		d1					Sürekli bir şeyleri okumam gerekiyor.
Comprehension-kavranabilirlik (anlaşılabilirlik)	d3	d2		d1			Bölgeler seçilemiyor. Çok fazla renk kullanılmış.	Anlaşılır değil, çok çok uzun süre bakmanız gerekiyor.
Accuracy - kesinlik	d2		d1, d3			3-4 puan arası.		Veri açısından tamam ama görsellik açısından kötü. Konumlandıma da kötü.
Efficiency - verimlilik	d2, d3			d1		Ne demek istediğini anlıyorum, en kurak yerler aklımda kalıyor, aşırı nemli yerleri görebiliyorum. Genel bir fikir veriyor.		

Utility - yararlılık	d2, d3		d1			Veriler kalite kontrolden geçmemiştir notu düşülmüş. Genel bir fikir vermek istemiş. Güneydoğu anadolu ne kadar kurak diyebiliyorum. Tek nemli yer de Karadeniz'miş gibi diyebiliyorum ama düşük.		Başlığı hiç değilse üste koysaymış. Renklendirmelere başlığa bakıyorum yararlı kesinlikle değil.
Clarity - netlik	d2, d3		d1			Bu alanlarda genel bir fikir veriyor. Biraz daha detaylı olabilirdi.		Renk daha iyi ayrıştırılabilirdi.
Speed - anlaşılma hızı	d3	d2		d1		Tek bir parametre veriyor ve anlıyorum ne demek istediğini.		
Soundness - doğruluk	d2		d1	d3		Kişisel yorumuma göre doğrudur gibi düşünüyorum ama…	Aşağıdaki notta verilerin kalite kontrolden geçmediği söylenmiş zaten.	Kaynak yine yok ama MGM'den geldiği için güveniyorum.
Engagement - ilgi çekicilik	d2, d3		d1					
Enjoyment - eğlenceli	d2, d3	d1						
Attractiveness - estetik-çekici olması	d1, d2, d3					Tasarlanmamış bir görsel, bütün veriler ortaya atılmış sadece. Anlatmak istediği şeyi renklerle ayırması veriyi iletmesini sağlıyor. O yüzden kavranabilirlik, verimlilik ve anlaşılma hızını yüksek verdik ama tasarlanmış olsaydı 10 kat daha iyi olabilirdi.		

Figure A.14 *Sixth Information Visualization Presented in Preliminary Study*



Source: Turkish State Meteorological Service, Retrieved from https://www.mgm.gov.tr/iklim/iklim-degisikligi.aspx?s=kuresel.

Table A.6 Participant Ratings and Comments for Sixth Information Visualization

INFO VIS Özellikleri (NO:20)	**1**	**2**	**3**	**4**	**5**	**Katılımcı yorumları d1**	**Katılımcı yorumları d2**	**Katılımcı yorumları d3**
Memorability - akılda kalıcılık		d1, d2	d3					Grafik belli ediyor kendini, bir sürü oklar vs. ama veriler akılda kalmaz. Görsel şekiller akılda kalır.
Comprehension-kavranabilirlik (anlaşılabilirlik)		d3	d1, d3			Spesifik bir kitleye yapıldığını varsayarsak. Çevrecilikle ilgili bir dergiye yapılmış veya Fen kitabında kullanılan bir görselse mesela anlaşılabilir olabilir. Ama şu an benim için, konuyla ilgisi olmayan biri için anlaşılabilirliği baya düşük. Radyasyonun nasıl dağıldığını anlıyorum. Çok spesifik bir grafik. Ben konuyu tam bilmediğim için kavranabilirlik üzerine çok yorum yapamıyorum o yüzden ortalama bir şey verelim.	İlkokul fen kitabı için yapılmış bir görsel ise bu çok kolay anlaşılmıyor.	Grafik göze çok çarpıyor.

Accuracy - kesinlik	d1, d3		d2			Bir infografik olduğu için veri grafiği olmadığı için genel olarak anlatılmış. Okların genişliğiyle yüzdeleri ayırmış gibi görünüyor ama bu oklar gerçekten orantılımı hiç sanmıyorum. Tasarımcı kendi yapmış gibi hissediyorum. Kesinliğine bir şey söyleyemiyorum.		
Efficiency - verimlilik		d1, d2, d3				Güneş ikonu, yer, kara ve deniz renkleri kullanılmış. Anlaşılırlığını kolaylaştırabilir.		Bir coğrafya hocası açısından mesela bir şeyler ifade edebilir ama hiçbir şey bilmeyen biri açısından bir şey ifade etmiyor.
Utility - yararlılık	d2	d1	d3			Bu haliyle yararlanamayız gibi geliyor bana.		Kaynak yok ama yine de bir yararlılık var bence
Clarity - netlik	d1, d2		d3					Grafik açıdan net ama verileri gösterme açısından zayıf.
Speed - anlaşılma hızı	d2	d1, d3				Genel olarak neyle ilgili olduğu anlaşılıyor aslında ama detayları anlayamıyorum. Grafik unsurlar kullanılarak biraz daha anlaşılır yapılabilirdi.	Oklar çok kafa karıştırıcı.	Çok zorlanıyorum. Grafiği okursam birşey anlaşılıyor.
Soundness - doğruluk	d1, d2, d3					Bilemiyorum çünkü konseptini bilemiyorum. Kim ne için yapmış bilemiyorum, orantıları da doğru değil.	Ben bu konunun uzmanı olmadığım için, konu hakkında bilgim olmadığı için aslında verilerin doğruluğu üzerine yorum yapamıyorum.	Karışık çok karışık. İnfografiğin ilk denemeleri gibi. Bugüne göre tasarımsal açıdan çok geride kalmış.
Engagement - ilgi çekicilik	d2	d1, d3				Grafik kaygı görülüyor. Gerçek hayata uygulandığından dolayı.		MGM'ye göre bir nebze daha iyi
Enjoyment - eğlenceli	d1, d2	d3						
Attractiveness - estetik-çekici olması		d1, d2, d3				Tasarım kaygısı olduğu için 2 veriyorum. Önceki hali eminim bakılmaz bir şeydir, en azından burada tasarım kaygısı var.	Bir önceki meteoroloji grafiklerine göre çok daha iyi. Ancak yine de karışık.	

APPENDIX B. IMAGES FROM THE CONDUCTED WORKSHOPS

Figure B.1 *Session 1 of Workshop 1*



Figure B.2 *Session 2 of Workshop 1*



Figure B.3 *Session 3 of Workshop 1*



Figure B.4 *Session 3 of Workshop 1 Continued*



Figure B.5 *Image from the Conducted Workshop 2*

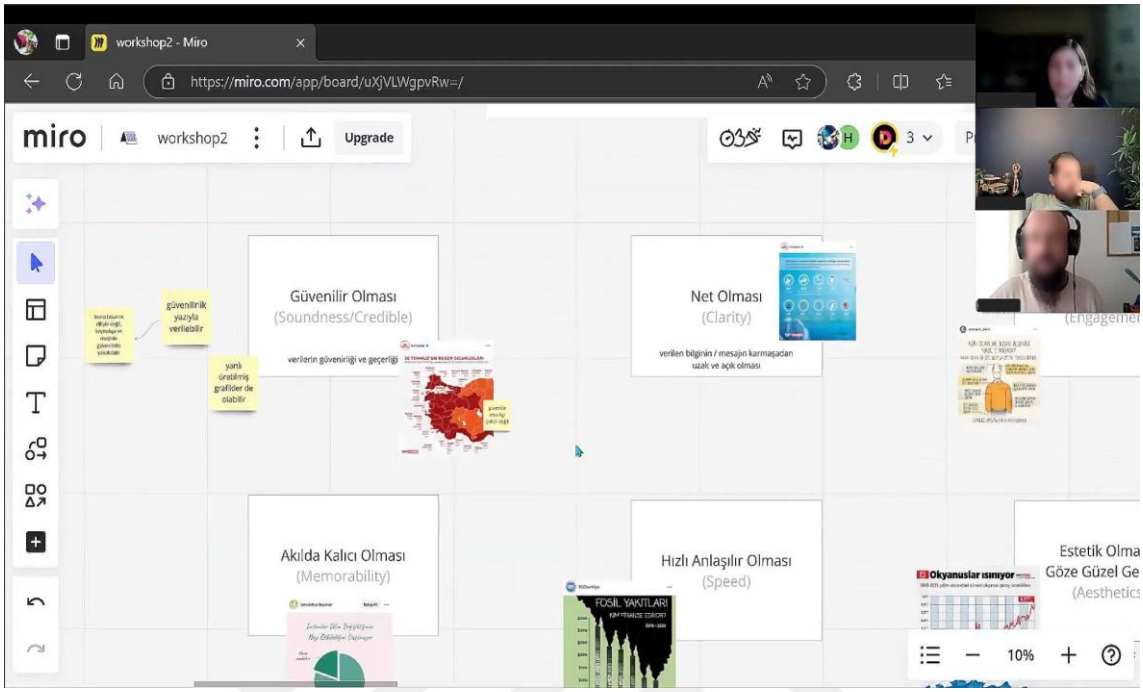


Figure B.6 *Image from the Conducted Workshop 3*

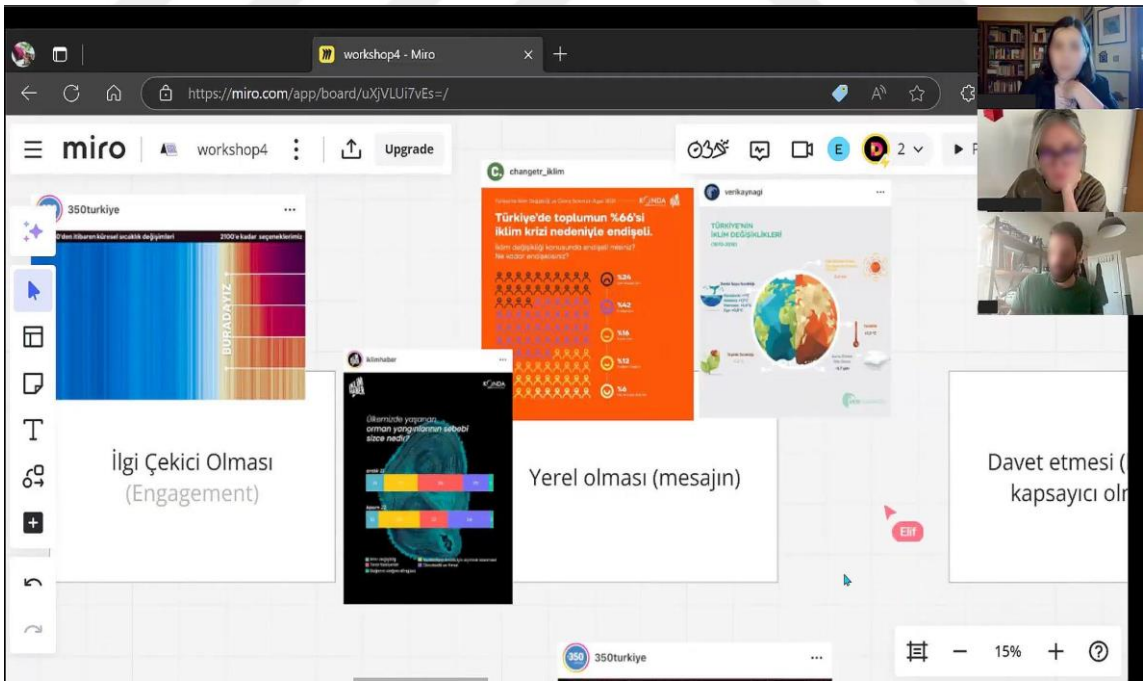
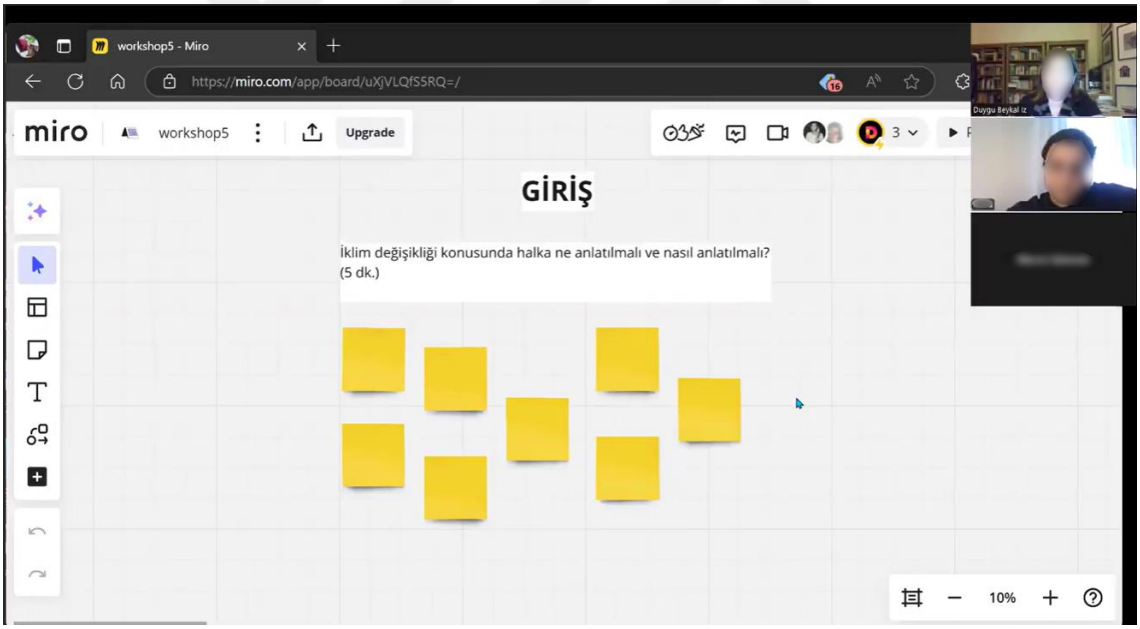


Figure B.7 *Image from the Conducted Workshop 4*

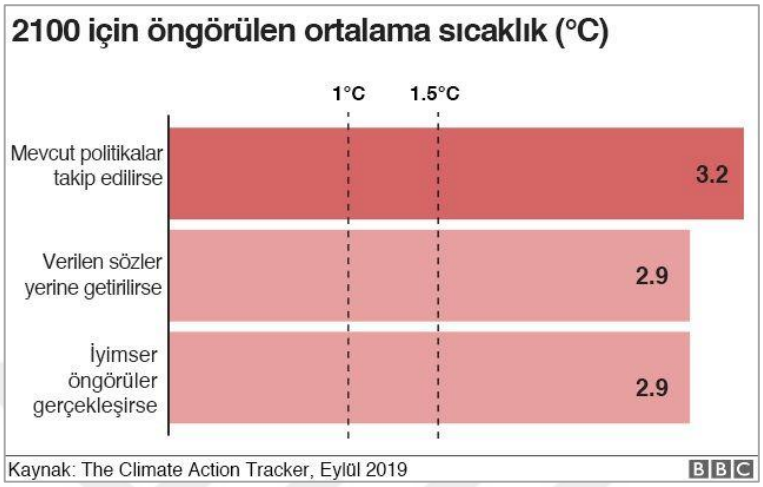


Figure B.8 *Image from the Conducted Workshop 5*



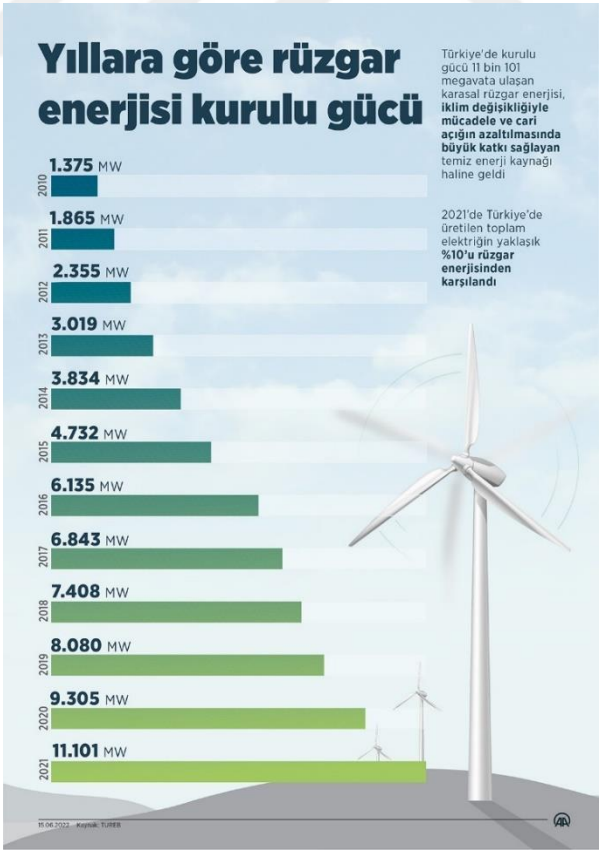
APPENDIX C. VISUAL MATERIALS USED IN WORKSHOPS

Figure C.1 *Projected Average Temperature for 2100*



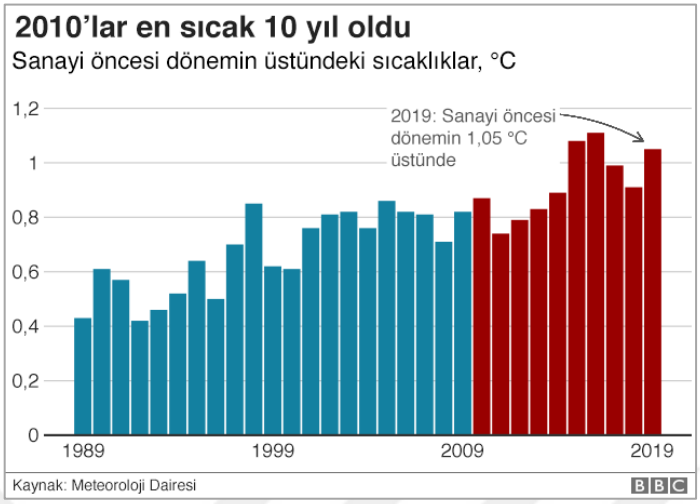
Source: BBC Turkce, September 2019, Retrived from https://www.bbc.com/turkce/haberler-dunya-50645185.

Figure C.2 *Installed Capacity of Wind Energy by Years*



Source: Anadolu Agency, June 15, 2022, Retrieved from https://www.aa.com.tr/tr/info/infographic/28630.

Figure C.3 *The 2010s Were the Hottest Decade*



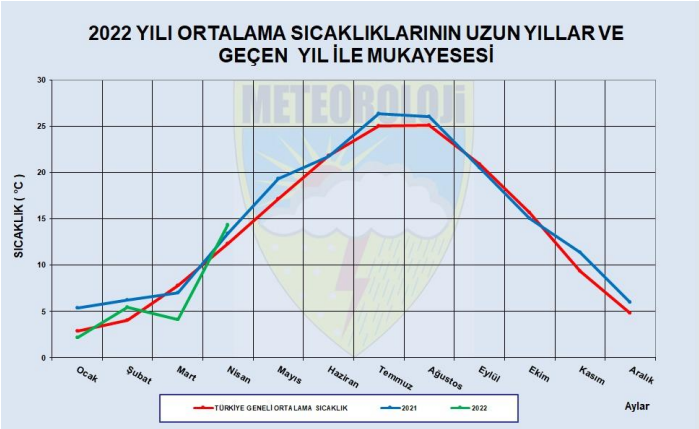
Source: BBC Turkce, January 15, 2020, Retrieved from https://www.bbc.com/turkce/haberler-dunya-51120658.

Figure C.4 *Distribution of Storms Experienced Throughout Turkey by Year*



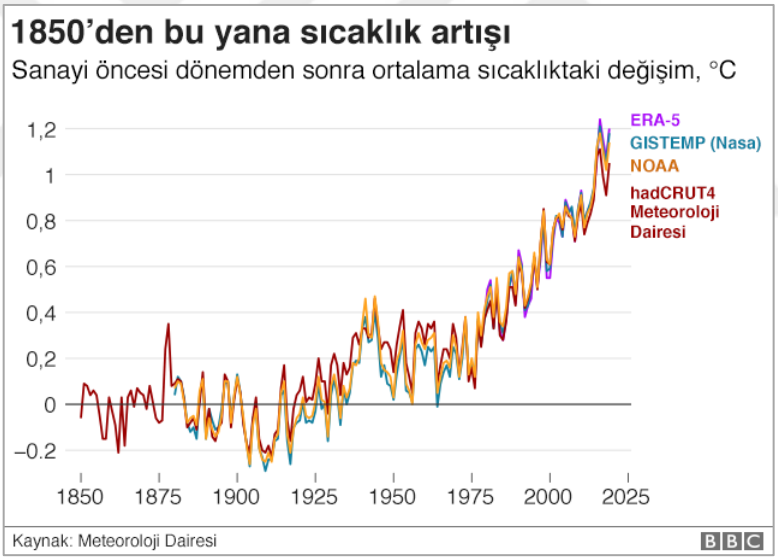
Source: TRT Haber, December 6, 2022, Retrieved from https://www.trthaber.com/haber/cevre/iklim-degisikligiyle-yazlar-uzuyor-kislar-kisaliyor-728624.html.

Figure C.5 *Comparison of Average Temperatures in 2022*



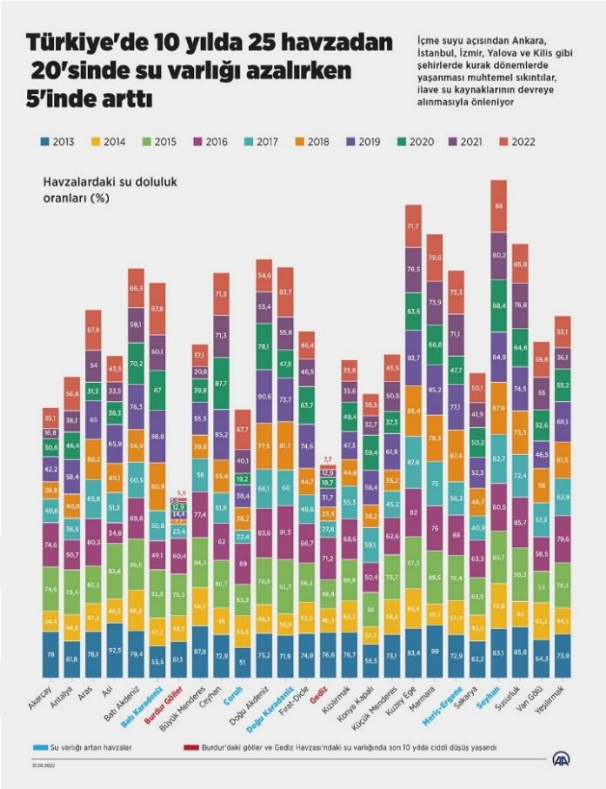
Source: Turkish State Meteorological Service, 2022, Retrieved from https://www.mgm.gov.tr/files/iklim/yillikiklim/2022-iklim-raporu.pdf.

Figure C.6 *Temperature Rise Since 1850*



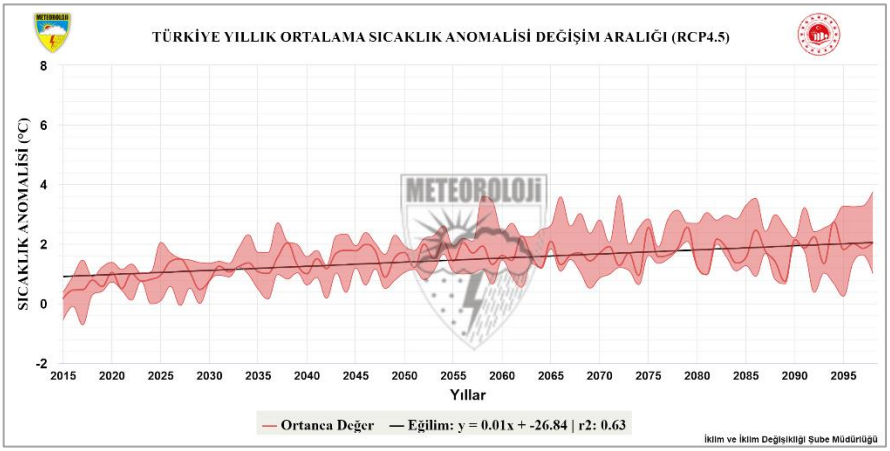
Source: BBC Turkce, January 15, 2020, https://www.bbc.com/turkce/haberler-dunya-51120658.

Figure C.7 *Comparison of Water Basins in Turkey*



Source: Anadolu Agency, August 31, 2022, Retrieved from https://www.aa.com.tr/tr/info/infografik/29620.

Figure C.8 *Turkey Annual Mean Temperature Anomaly Change Range*



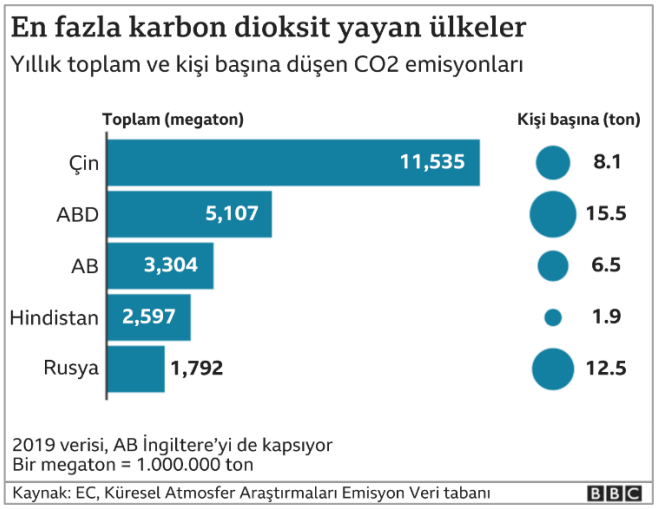
Source: Turkish State Meteorological Service, Retrieved from https://www.mgm.gov.tr/iklim/iklim-degisikligi.aspx?s=projeksiyonlar.

Figure C.9 *The Most Signed Climate Campaigns in 2022*



Source: Change.org Türkiye-iklim, January 3, 2023, Retrieved from https://www.instagram.com/p/Cm8XVF2IfQ1/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.10 *The Most Carbon Dioxide Emitting Countries*



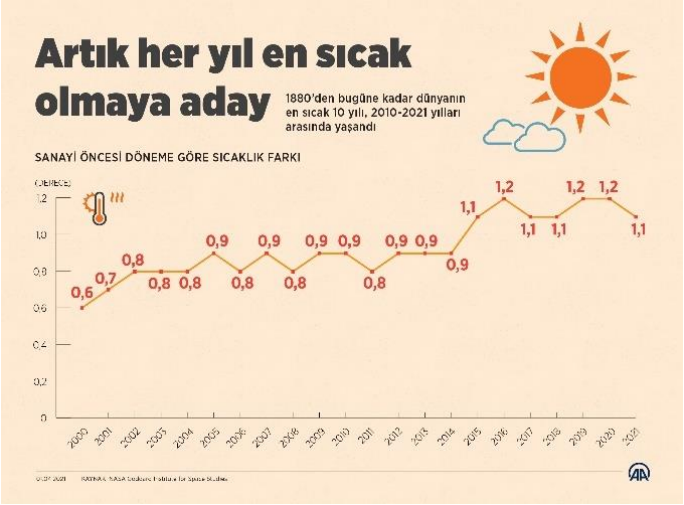
Source BBC Turkce, October 30, 2021, Retrieved from https://www.bbc.com/turkce/haberler-dunya-59088481.

Figure C.11 *How Heat Waves Affect Human Body*



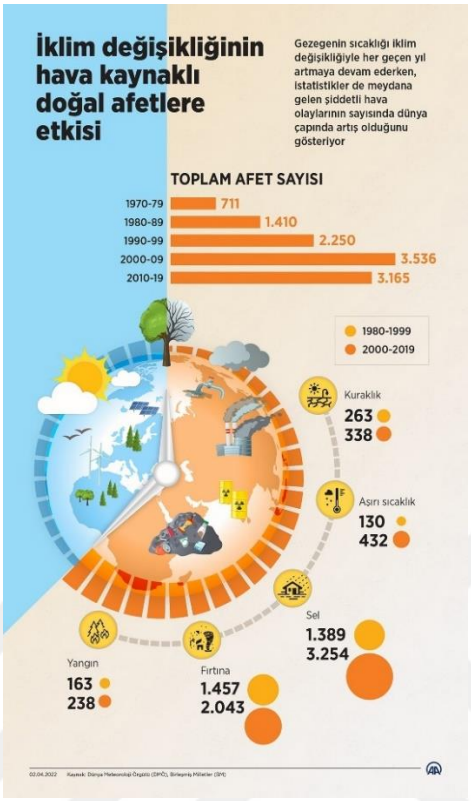
Source: Change.org Türkiye-iklim,August 21, 2023, Retrieved from https://www.instagram.com/p/CwMjvcvoF6f/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.12 *Every Year Is a Candidate for the Hottest Year*



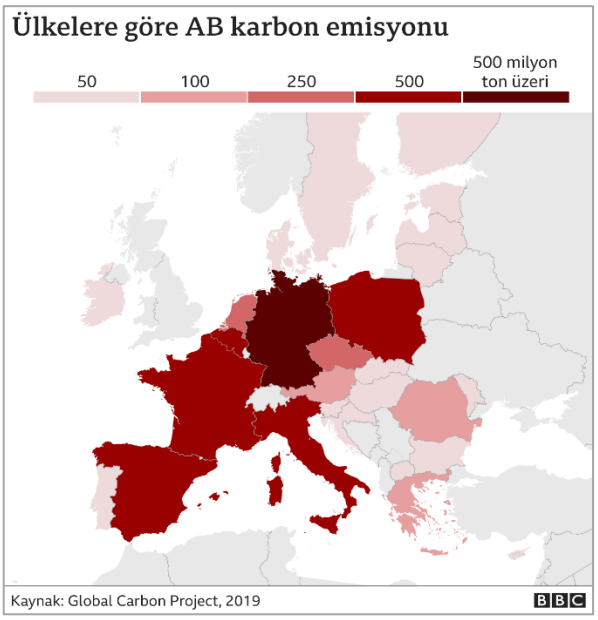
Source: Anadolu Agency, April 1, 2022, Retrieved from https://www.aa.com.tr/tr/yesilhat/iklim-degisikligi/artik-her-yil-en-sicak-olmaya-aday/1814922.

Figure C.13 *The Effect of Climate Change on Weather Sourced Natural Disasters*



Source: Anadolu Agency, April 2,2022, Retrieved from https://www.aa.com.tr/tr/cevre/iklim-degisikligiyle-felaketler-siddetlenecek-siklasacak-ve-yayginlasacak-uyarisi/2553204.

Figure C.14 *EU Carbon Emissions by Country*



Source: BBC Turkce, October 30, 2021, Retrieved from https://www.bbc.com/turkce/haberler-dunya-59088481.

Figure C.15 *Heat Stress Alert for Nearly 900 million Farmers*



Source: Anadolu Agency, July 12, 2023, Retrieved from https://www.aa.com.tr/tr/yesilhat/iklim-degisikligi/yaklasik-900-milyon-ciftci-icin-sicaklik-stresi-alarmi/1820704.

Figure C.16 *Which Countries Does the EU Send Its Garbage to*



Source: Change.org Türkiye-iklim, December 3, 2022 Retrieved from https://www.instagram.com/p/ClsrrhSIGfB/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.17 *Which Country Pollutes the World to What Extent*



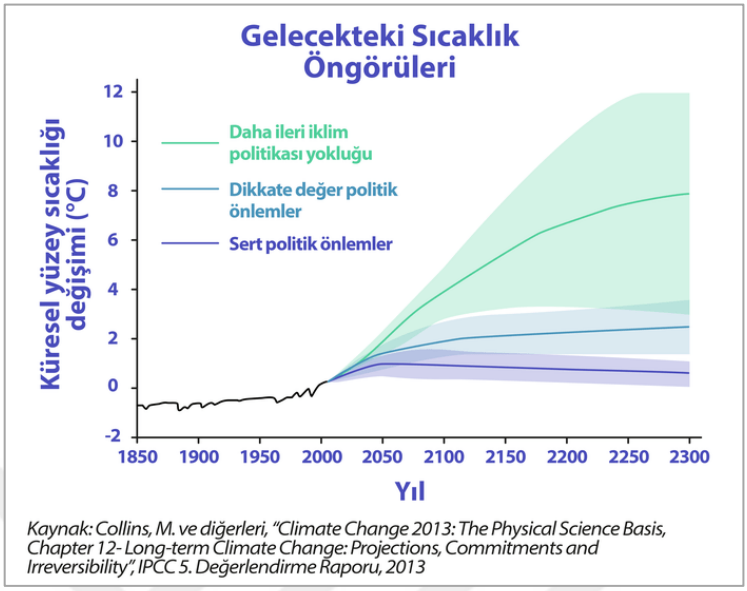
Source: TRT Haber, October 21, 2021, Retrieved from https://www.trthaber.com/haber/cevre/2021de-artan-karbon-saliniminda-zengin-ulkelerin-rolu-619050.html.

Figure C.18 *66% of the Public in Turkey Is Anxious Because of Climate Crisis*



Source: KONDA and İklim Haber, February 15, 2022 Retrieved from https://www.instagram.com/p/CaANM0QNgY5/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.19 *Future Temperature Predictions*



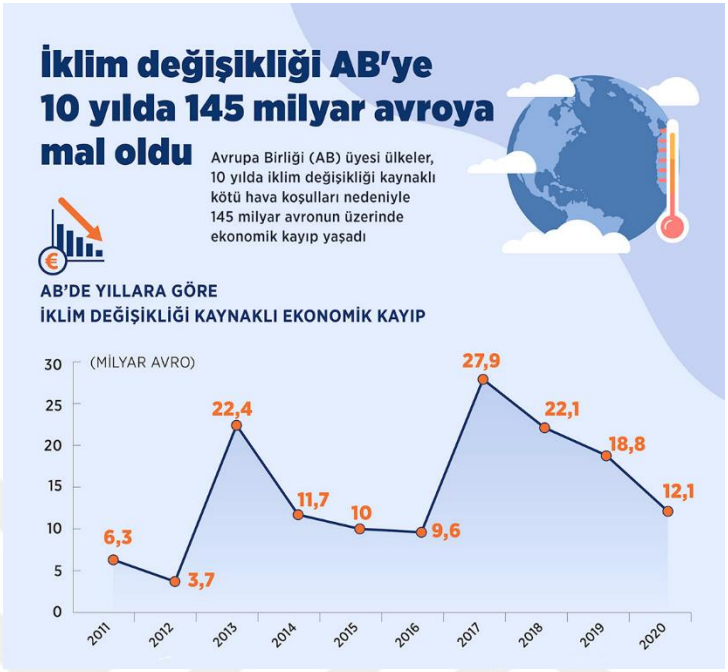
Source: Data from IPCC 2013 Report, translated into Turkish and re-posted on Instagram, Retrieved from https://climatescience.org/advanced-climate-climate-models.

Figure C.20 *Environmental Disasters Caused by Humans*



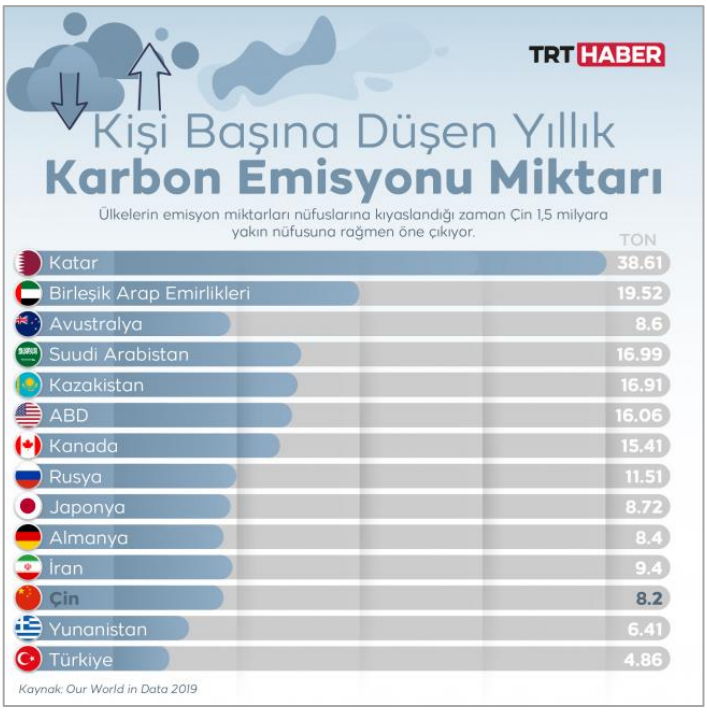
Source: Change.org, February 12, 2022, Retrieved from https://www.facebook.com/Change.orgTurkey/photos/a.241886872614594/2496547313815194/?type=3&eid=ARCF_R4oWM4zxfaEoyKGx4KIRh7bAxxWDkYbsLu8PFvgIR79JdD451QBY2Edd-qCvXc-GF8wx_45_nnK.

Figure C.21 *Climate Change Cost EU 145 billion Euros in the Last Decade*



Source: Anadolu Agency, October 24, 2022, Retrieved from https://www.aa.com.tr/tr/dunya/iklim-degisikligi-abye-10-yilda-145-milyar-avroya-mal-oldu/2719451.

Figure C.22 *Yearly Carbon Emissions per Person*



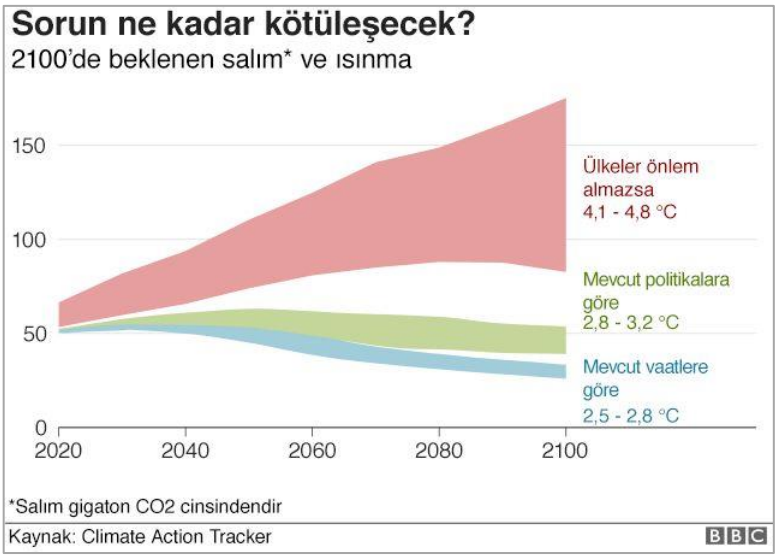
Source: TRT Haber, November 9, 2021, data from 2019, Retrieved from https://www.trthaber.com/haber/cevre/dunyanin-gelecegi-cine-mi-bagli-624158.html.

Figure C.23 *3 Out of 4 People in Turkey Think Climate Crisis Cause Extreme Weather Events*



Source: KONDA and İklim Haber, February 15, 2022, Retrieved from https://www.instagram.com/p/CZ_01DWrpIr/?utm_source=ig_web_copy_link.

Figure C.24 *How Bad Will the Problem Get*



Source: BBC Turkce, January 17, 2020, Retrieved from https://www.bbc.com/turkce/haberler-dunya-51133428.

Figure C.25 *Increase Rate of Carbon Emissions of China by Years*



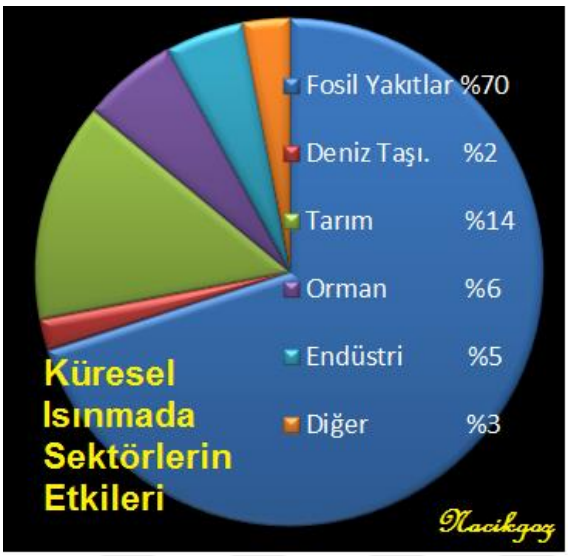
Source: TRT Haber, November 9, 2021, Retrieved from https://www.trthaber.com/haber/cevre/dunyanin-gelecegi-cine-mi-bagli-624158.html.

Figure C.26 *Which Countries Do EU Countries Send Their Waste to*



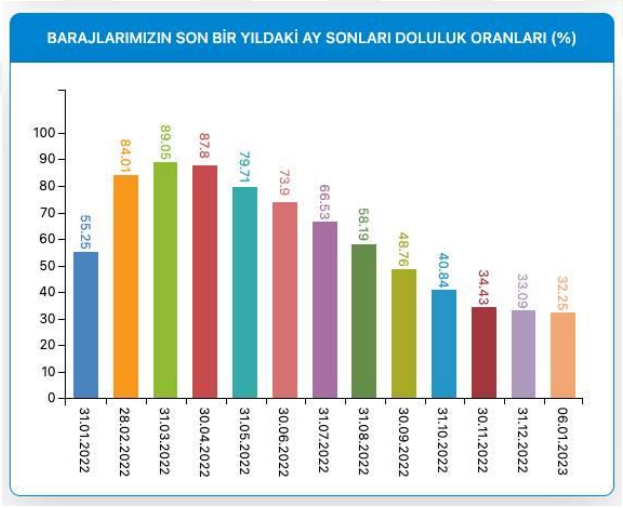
Source: Veri Kaynağı, December 16, 2022, Retrieved from https://www.instagram.com/p/CmORsoVqEOZ/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.27 *Effects of Sectors on Global Warming*



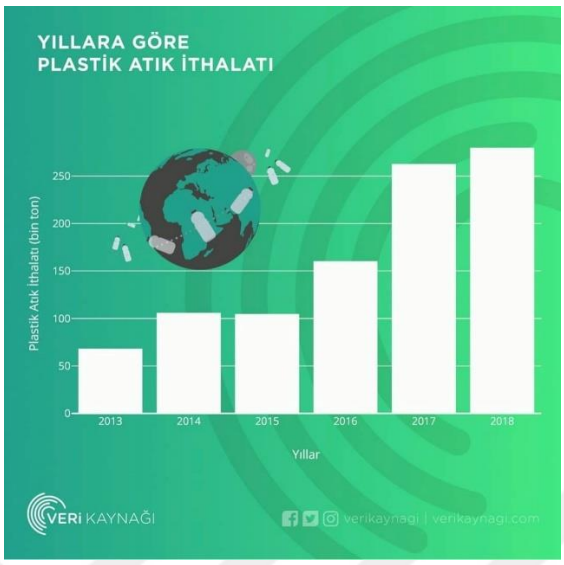
Source: Published by Nazimi Acikgoz, November 5, 2019, Retrieved from https://x.com/nazimiacikgoz/status/1191634859992715265/photo/1.

Figure C.28 *End-of-Month Reservoir Fill Rates Over the Past Year*



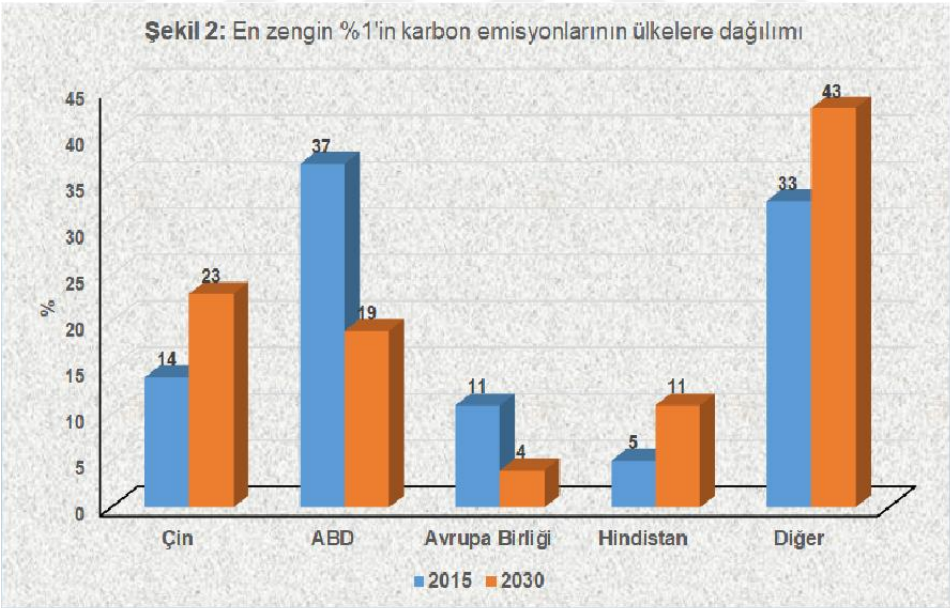
Source: ISKI shared by Yeşil Gazete, February 24, 2023, Retrieved from https://yesilgazete.org/iskiden-su-tasarrufu-cagrisi/.

Figure C.29 *Plastic Waste Exports by Years*



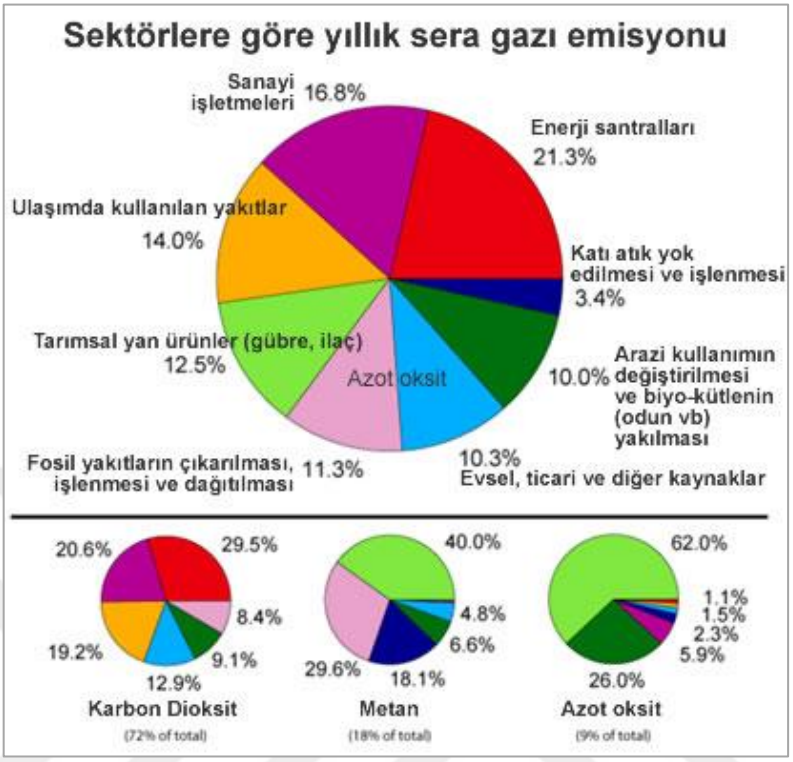
Source: Veri Kaynağı, August 2, 2019, Retrieved from https://www.instagram.com/p/B0pr--HnXFQ/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.30 *Distribution of Carbon Emissions of the Richest 1% by Country*



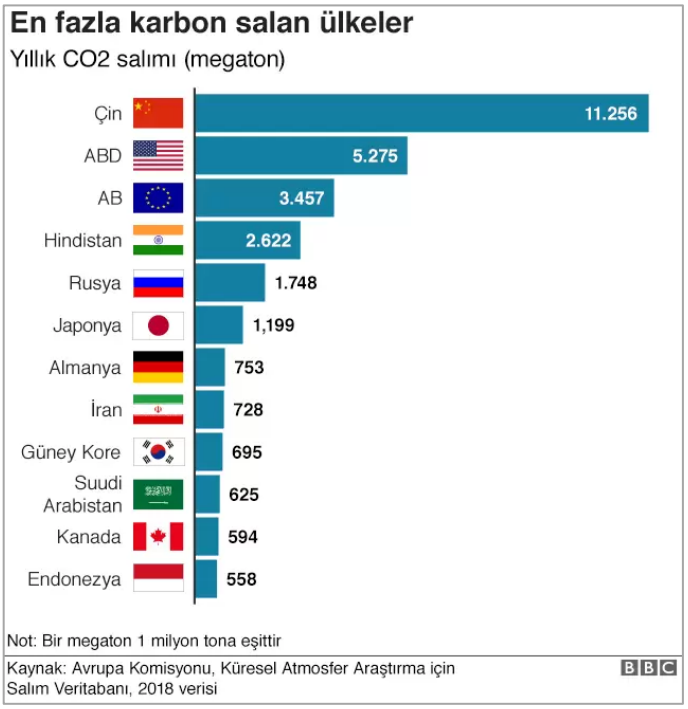
Data Source: https://www.oxfam.org/en/press-releases/carbon-emissions-richest-1-set-be-30-times-15degc-limit-2030 translated into Turkish.

Figure C.31 *Annual Greenhouse Gas Emissions by Sector*



Source: http://www.cevreciyiz.com/makale-detay/629/kuresel-isinma-kiyamet-gunune-dogru.

Figure C.32 *Countries Emitting the Most Carbon*



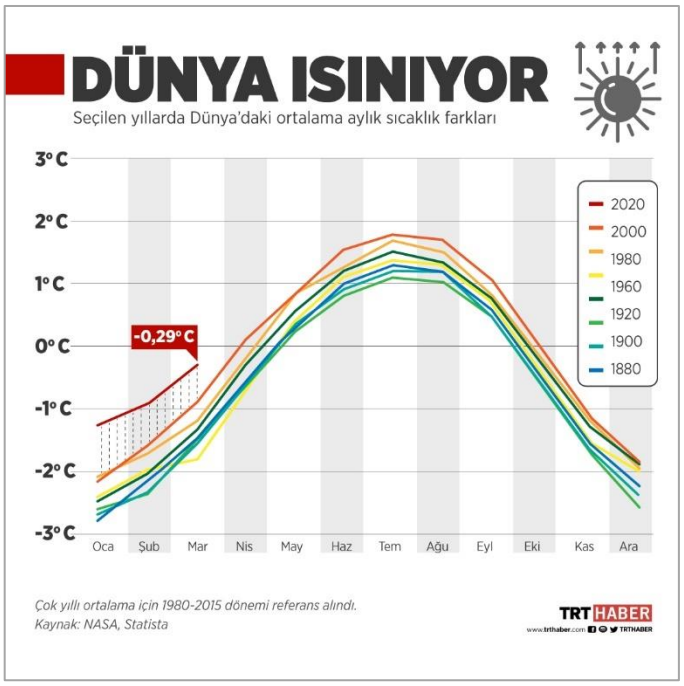
Source: BBC Turkce, January 17, 2020, https://www.bbc.com/turkce/haberler-dunya-51133428.

Figure C.33 *Climate Change of Turkey*



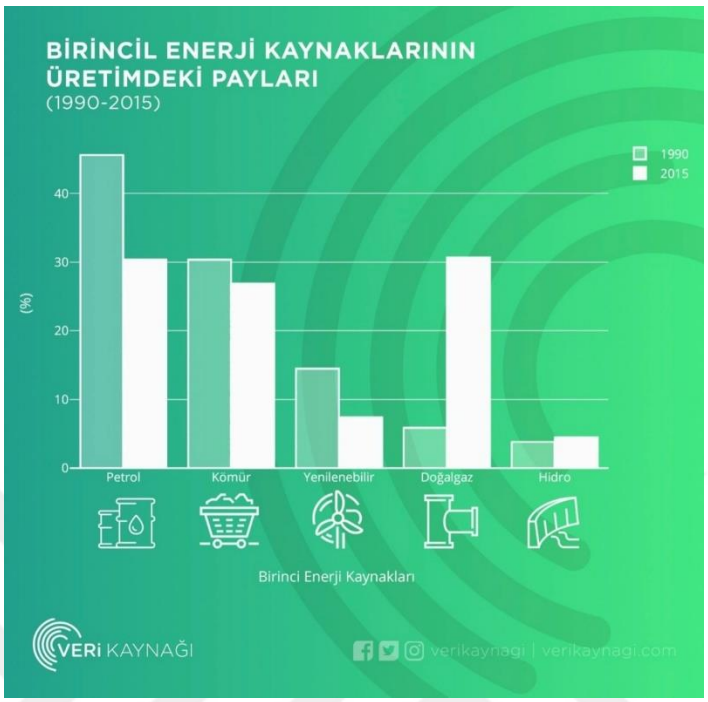
Source: Veri Kaynağı, September 23, 2019, Retrieved from https://www.instagram.com/p/B2v2fQmH9-C/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.34 *The Earth Is Warming*



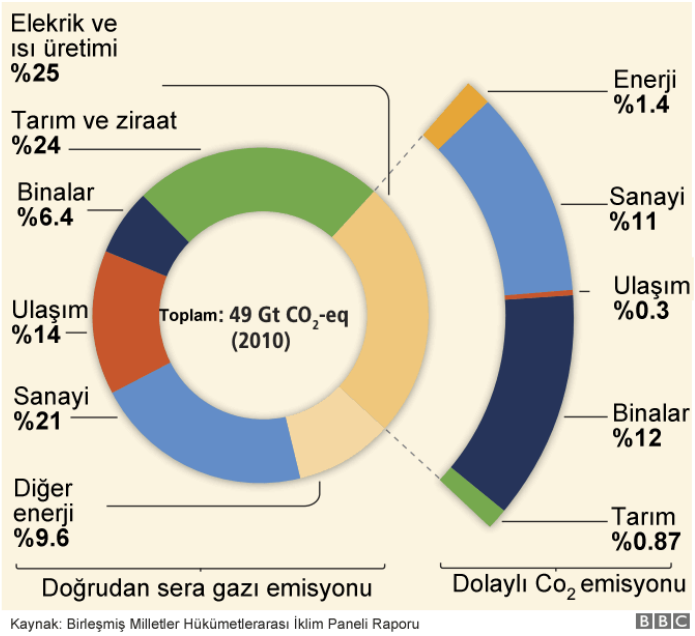
Source: TRT Haber, May 12, 2020, Retrieved from https://www.facebook.com/trthaber/posts/k%C3%BCresel-%C4%B1s%C4%B1nma-iklim-de%C4%9Fi%C5%9Fikli%C4%9Fi-bunlar-kula%C4%9Fa-s%C4%B1radan-ifadeler-gibi-gelse-de-as/3356446424373685/.

Figure C.35 *Shares of Primary Energy Resources in Production*



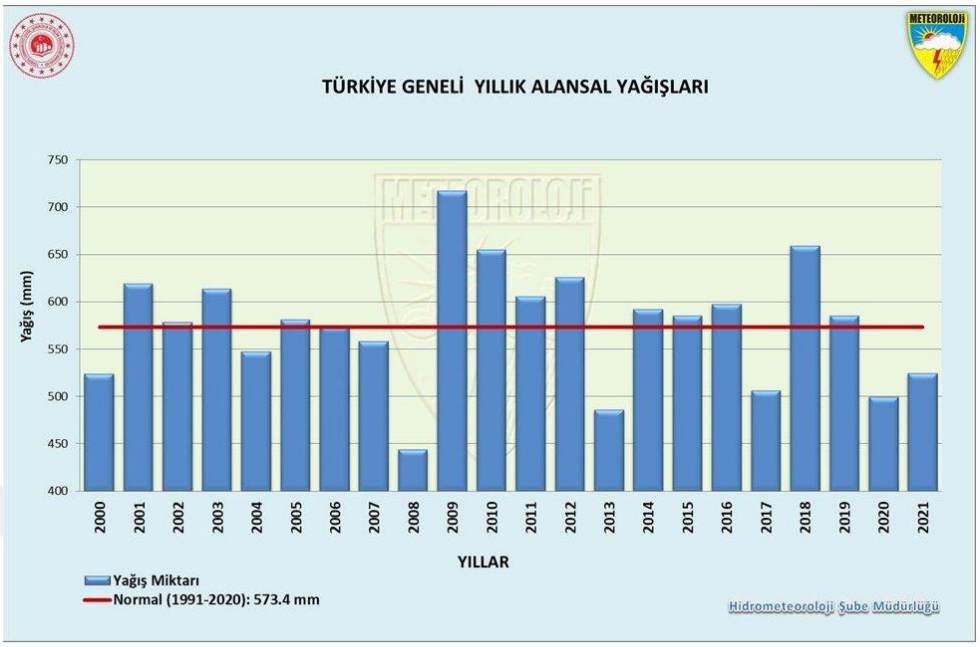
Source: Veri Kaynağı, November 14, 2019, Retrieved from https://www.instagram.com/p/B41tu9miqi6/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.36 *Greenhouse Gas and CO2 Emissions*



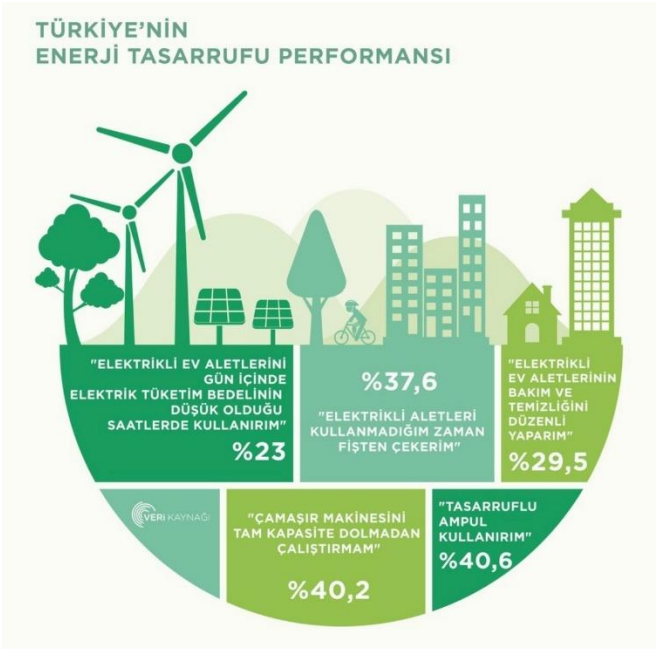
Source: BBC Turkce, October 22, 2018, Retrieved from https://www.bbc.com/turkce/haberler-dunya-45938984.

Figure C.37 *Annual Areal Precipitation in Turkey*



Source: Ministry of Environment, Urbanization and Climate Change, General Directorate of Meteorology; 2023 Retrieved from https://cevreselgostergeler.csb.gov.tr/yagis-i-85728.

Figure C.38 *Turkey's Energy Saving Performance*



Source: Veri Kaynağı, January 13, 2020, Retrieved from https://www.instagram.com/p/B7QBr6_iNWR/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.39 *Carbon Emissions per Kilograms of Food Products*



Source: BBC Turkce, October 26, 2021, Retrieved from https://www.bbc.com/turkce/haberler-dunya-59046140.

Figure C.40 *Environmental Awareness in Turkey*



Source: Veri Kaynağı, October 13, 2020, Retrieved from https://www.instagram.com/p/CGRlOrkCQs0/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.41 *Every Decade Is Warmer Than the Previous One*



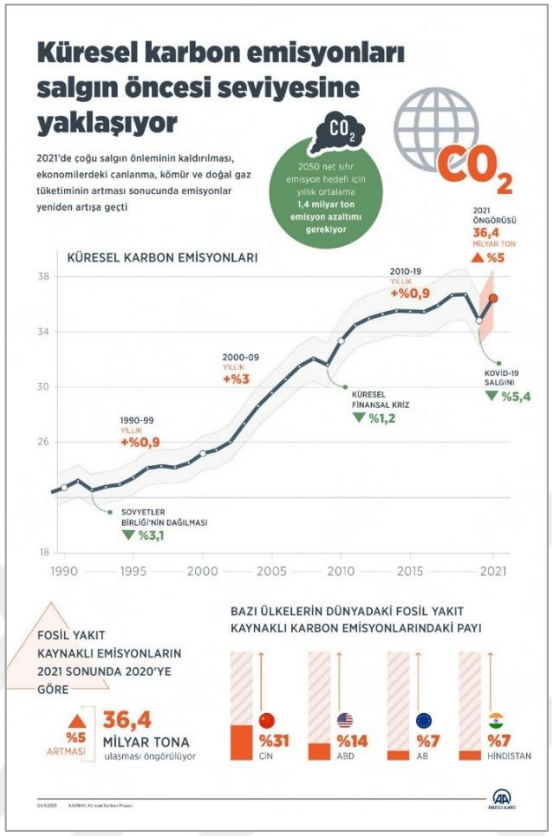
Source: TRT Haber, January 26, 2021, Retrieved from https://www.facebook.com/photo.php?fbid=4118224198195900&id=127630700588623&set=a.242947575723601.

Figure C.42 *Do You Think Irregular Weather Conditions Increased Recently*



Source: Veri Kaynağı, November 4, 2020, Retrieved from https://www.instagram.com/p/CHKO7fDq2jY/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.43 *Global Carbon Emissions Approach Pre-Pandemic Levels*



Source: Anadolu Agency, November 4, 2021, Retrieved from https://www.aa.com.tr/tr/cevre/kuresel-karbon-emisyonlari-salgin-oncesi-seviyesine-yaklasiyor/2411474.

Figure C.44 *Climate Situation in Turkey*



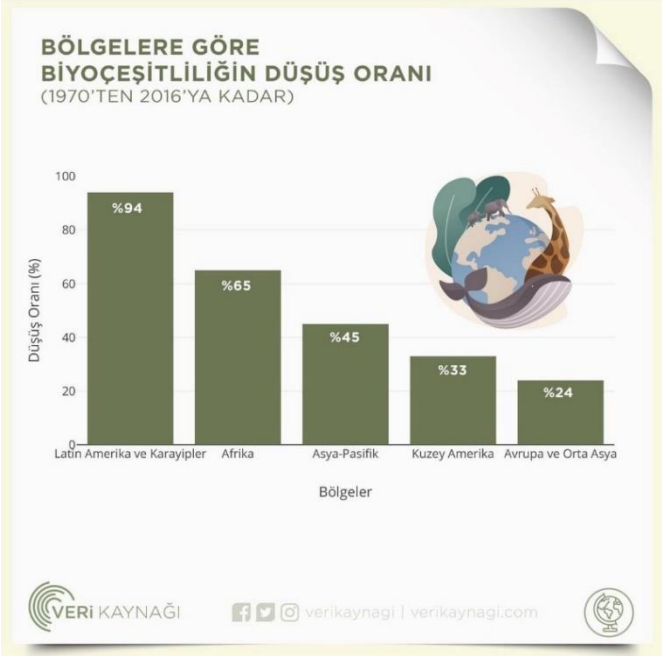
Source: Veri Kaynağı, March 23, 2021, Retrieved from https://www.instagram.com/p/CMwI91DqcZW/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.45 *The Most Carbon-Emitting Countries*



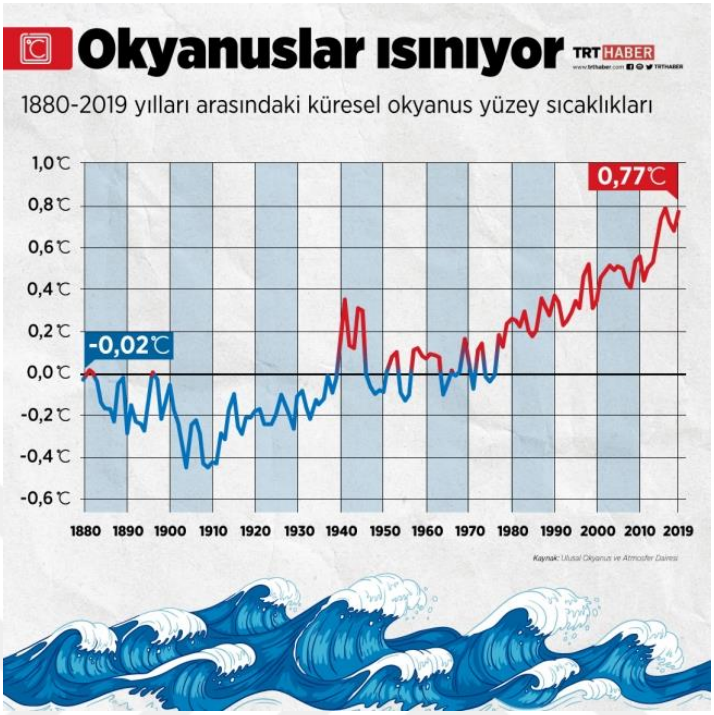
Source: Anadolu Agency, May 15, 2022, Retrieved from https://www.aa.com.tr/tr/cevre/kuresel-karbonun-yarisindan-fazlasini-uc-ulke-saliyor/2588391.

Figure C.46 *Rate of Decline of Biodiversity by Region*



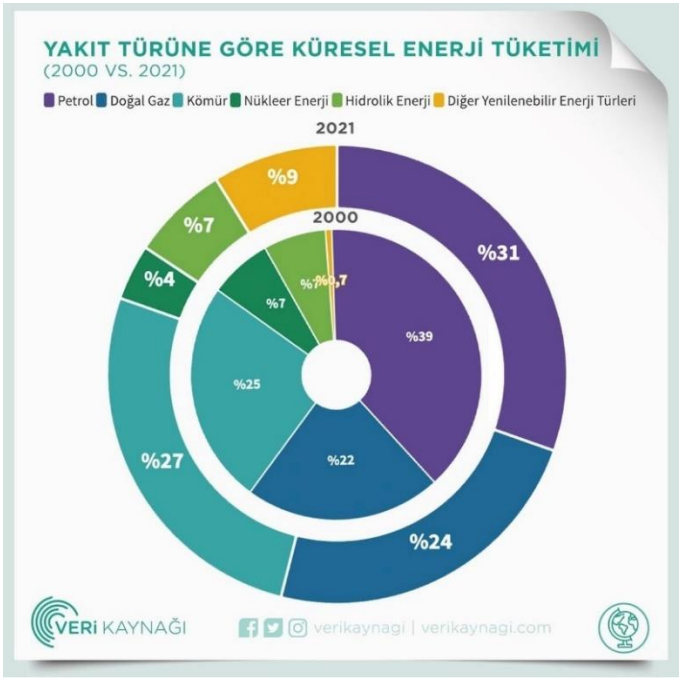
Source: Veri Kaynağı, September 26, 2022, Retrieved from https://www.instagram.com/p/Ci9freFKLb7/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.47 *Oceans Are Warming*



Source: TRT Haber, June 16, 2020, Retrieved from https://www.trthaber.com/haber/infografik/okyanuslar-isiniyor-493377.html.

Figure C.48 *Global Energy Consumption by Fuel Type*



Source: Veri Kaynağı, October 13, 2022, Retrieved from https://www.instagram.com/p/CjpRClYqVw1/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.49 *Countries to Which the EU Exports Its Waste*



Source: Doğru Veri, 2022, Retrieved from https://www.instagram.com/p/Cxa9WTuNcqn/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.50 *European Countries That Produce the Most Waste*



Source: Doğru Veri, August 31, 2023, Retrieved from https://www.instagram.com/p/Cwndcx3NrU0/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.51 *Countries that Dump Most Plastic Waste into Oceans*



Source: Doğru Veri, August 5, 2023, Retrieved from https://www.instagram.com/p/Cvkgx_bttsv/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.52 *Wind Power Capacity by Country*



Source: Doğru Veri, April 24, 2023, Retrieved from https://www.instagram.com/p/CrbUbvutby2/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.53 *Countries That Pollute Oceans the Most with Plastic Waste*



Source: Doğru Veri, April 10, 2023, Retrieved from https://www.instagram.com/p/Cq2TAxboA2T/?utm_source=ig_web_copy_link.

Figure C.54 *Three-Month Drought Map*



Source: Doğru Veri, March 1, 2023, Retrieved from https://www.instagram.com/p/CpPnuL8stgo/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.55 *Methane Emissions*



Source: Istanbul Climate Save, October 9, 2023, Retrieved from https://www.instagram.com/p/CyL2mAZoVkG/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.56 *Environmental Impacts of Milk by Type*



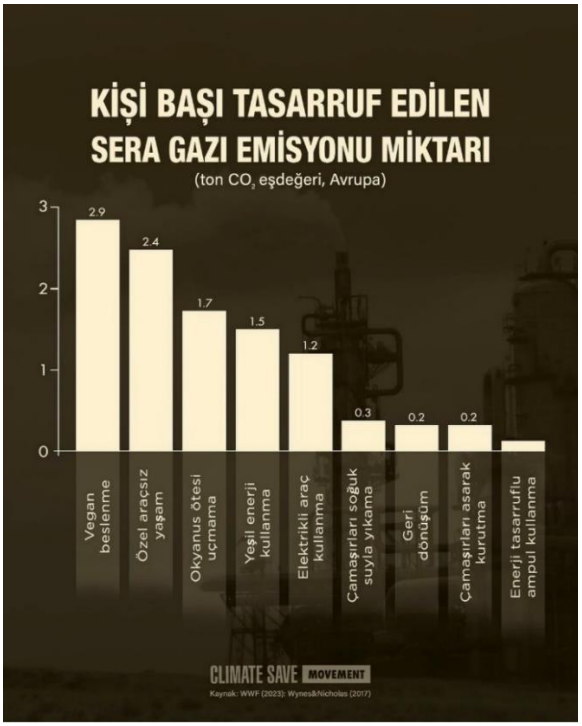
Source: Istanbul Climate Save, August 22, 2023, Retrieved from https://www.instagram.com/p/CwQTl2iqqIw/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.57 *How Much Does Your Food Cost the World*



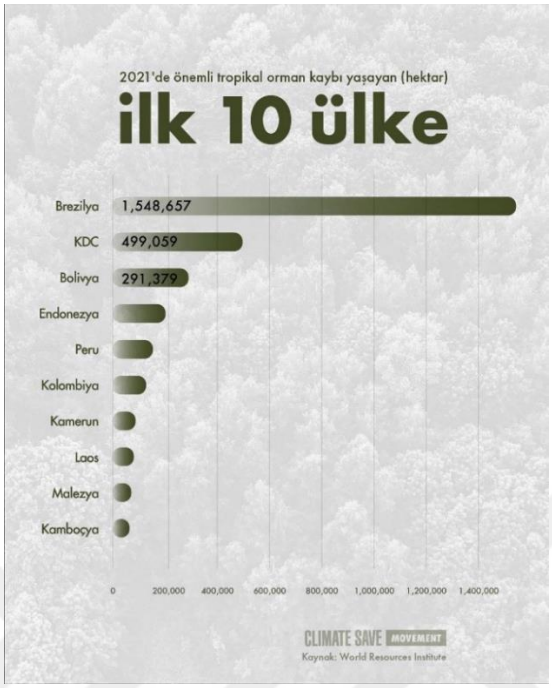
Source: Istanbul Climate Save, July 30, 2023, Retrived from https://www.instagram.com/p/CvU5RKJIPeR/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.58 *The Amount of Greenhouse Gas Emissions Saved by Person*



Source: Istanbul Cliamte Save, April 20, 2023, Retrieved from https://www.instagram.com/p/CrQ47WsIb8V/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.59 *Top-10 Countries Experiencing Significant Tropical Forest Loss in 2021*



Source: Istanbul Climate Save, March 28, 2023, Retrieved from https://www.instagram.com/p/CqVhXK-oBRD/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.60 *Humanity's Ecological Footprint Based on Land Use and Activities*



Source: Istanbul Climate Save, March 22, 2023, Retrieved from https://www.instagram.com/p/CqE9s4EIQOm/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.61 *Global Methane Emissions*



Source: Istanbul Climate Save, February 2, 2023, Retrieved from https://www.instagram.com/p/CoKmyh0ILOS/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.62 *Carbon Dioxide Equivalent Amount*



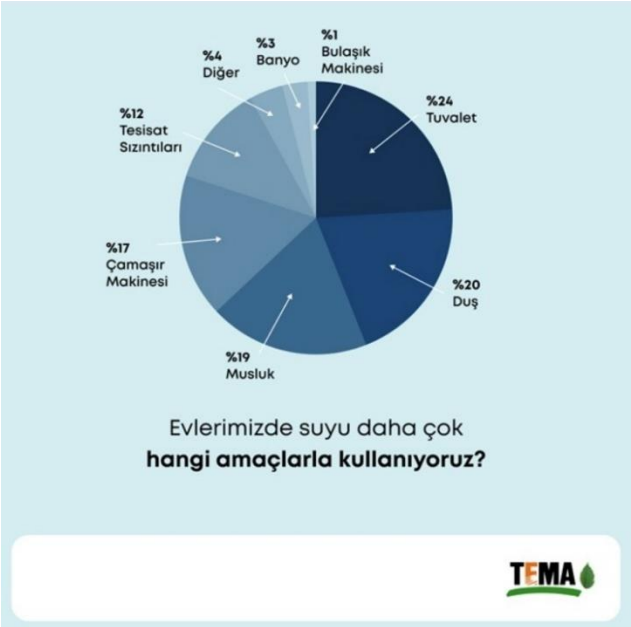
Source: Istanbul Climate Save, January 25, 2023, Retrieved from https://www.instagram.com/p/Cn16bGOo7CQ/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.63 *For 1 Liter of Milk 1000 Liters of Water Is Used*



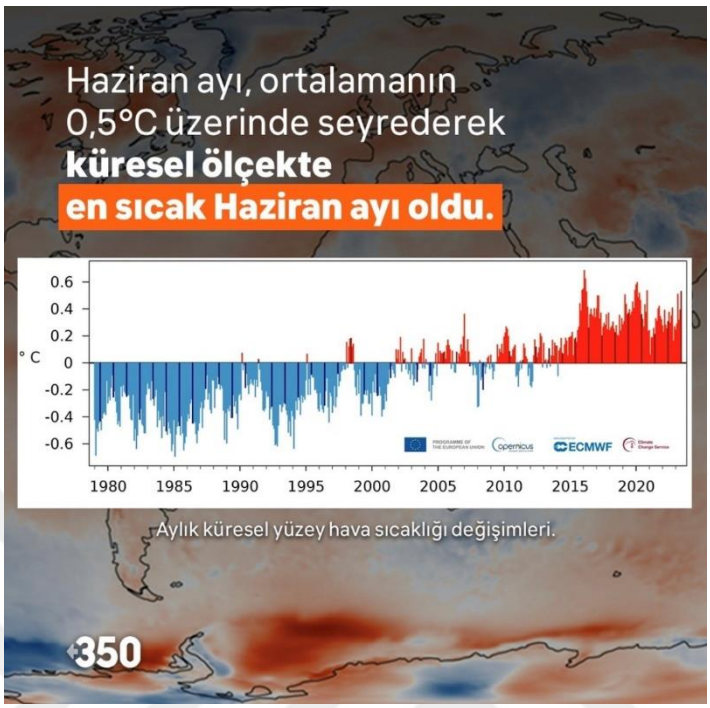
Source: Istanbul Climate Save, October 31, 2023, Retrieved from https://www.instagram.com/p/CzEdBSfILZl/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.64 *For What Purposes Do We Use Water Most in Our Home*



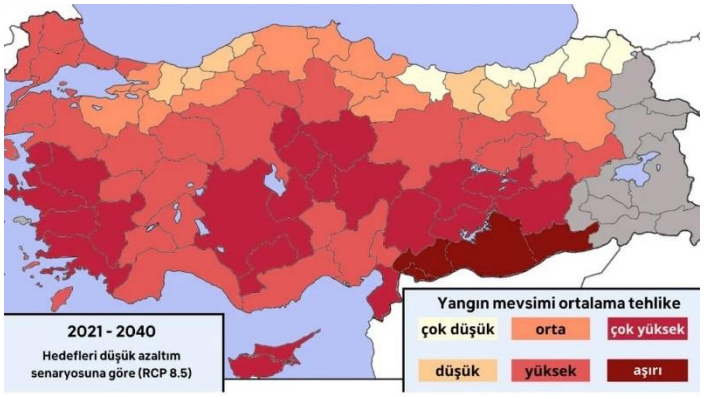
Source: TEMA, September 13, 2023, Retrieved from https://www.instagram.com/p/CxISfbZOc4Y/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.65 *June Was the Hottest Month*



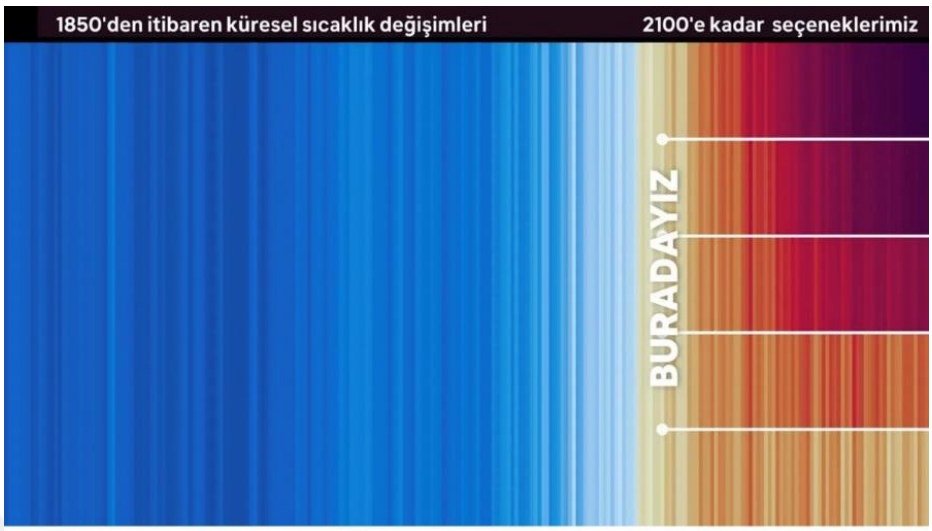
Source: 350 Türkiye, July 11, 2023, Retrieved from https://www.instagram.com/p/CujdFNrq4VI/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.66 *Fire Season Average Danger Rates*



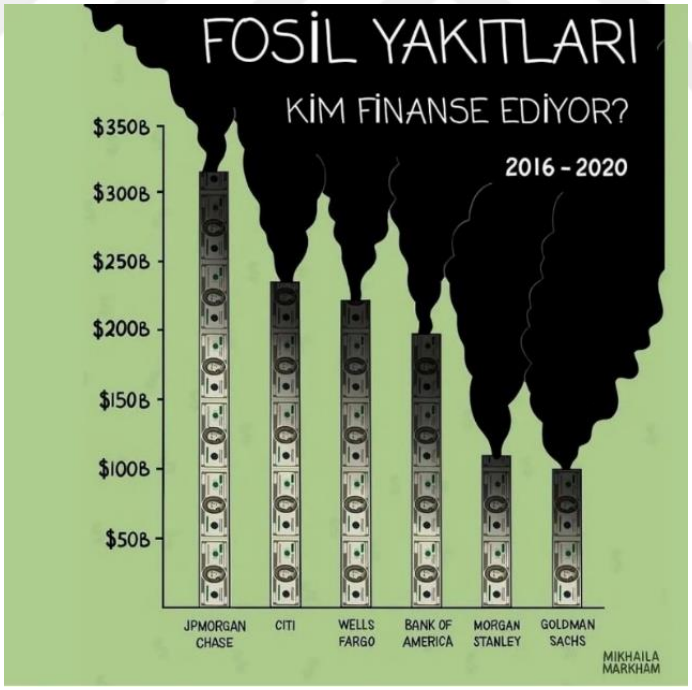
Source: 350 Türkiye, June 22, 2022, Retrieved from https://www.instagram.com/p/CfGRAhOgBzt/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.67 *Warming Stripes*



Source: 350 Türkiye, May 11, 2022, Retrieved from https://www.instagram.com/p/Cdabt78o-R0/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.68 *Who Finances Fossil Fuels*



Source: 350 Türkiye, October 3, 2021, Retrieved from https://www.instagram.com/p/CUlBBnTACNK/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.69 *70% of Turkish Society Is Concerned About Climate Change*



Source: KONDA and İklim Haber, 2020, Retrieved from https://www.sivilsayfalar.org/2020/11/26/turkiyenin-yarisina-gore-iklim-krizi-pandemiden-daha-tehlikeli/.

Figure C.70 *August 2023 Temperature Comparison*



Source: 350 Türkiye, September 26, 2023, Retrieved from https://www.instagram.com/p/CxqTbalt1Db/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.71 *Three-Month Drought Map*



Source: GZT, 2023, Retrieved from https://www.instagram.com/p/CpI5gBZI249/?utm_source=ig_web_copy_link.

Figure C.72 *Greenhouse Gasses Emitted per 100 Grams of Protein Produced*



Source: Istanbul Climate Save May 4, 2023 https://www.instagram.com/p/Cr091SEIS4H/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.73 *10 Commonly Consumed Foods That Are Harmful to Climate*



Istanbul Climate Save, December 23. 2022 https://www.instagram.com/p/CmhHzytIPJo/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.74 *According to 47% of Us Difficulty in Access to Water Is Related to Climate Crisis*



Source: Yuvam Dünya, March 23, 2023, Retrieved from https://www.instagram.com/p/CqIdHh1KNii/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.75 *63 % of Us Relate Extreme Weather Events with Climate Crisis*



Source: Yuvam Dünya, March 29, 2023, Retrieved from https://www.instagram.com/p/CqYA_BkqiXR/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.76 *How Many Worlds Would Be Needed If We All Lived as These Countries*



Source: Yuvam Dünya, June 23, 2022, Retrieved from https://www.instagram.com/p/CfJW5PYNkq6/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.77 *Hottest Month Ever*



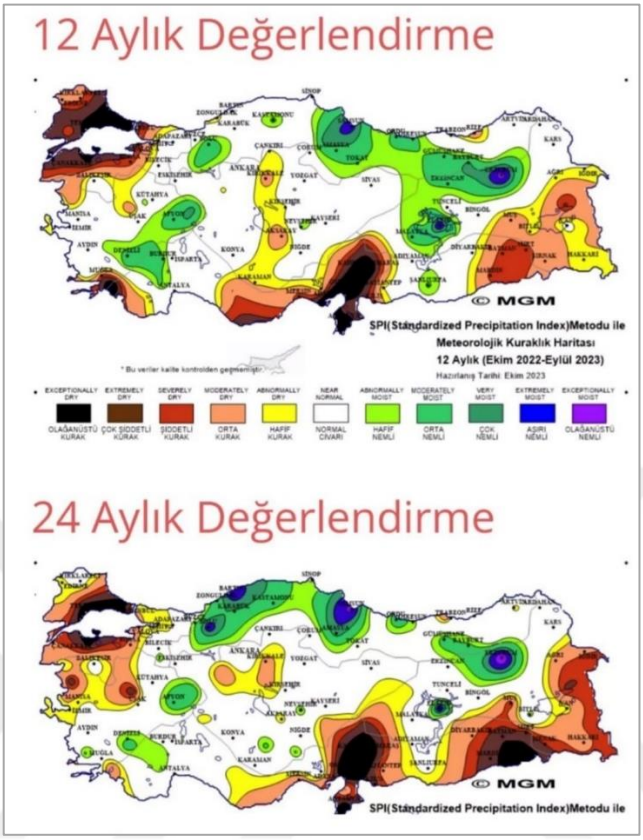
Source: Greenpeace Türkiye, August 9, 2023, Retrieved from https://www.instagram.com/p/CvuRSIjM0uU/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.78 *What the People Think Climate Change Affects*



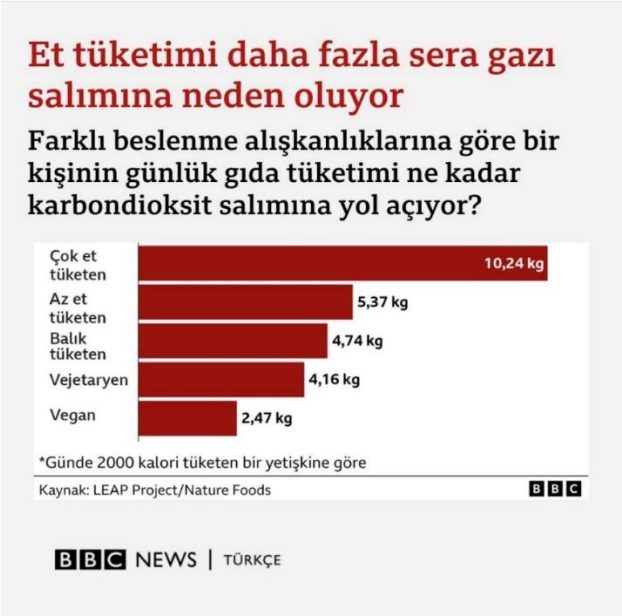
Source: Ben de Burdayım, March 10, 2023, Retrieved from https://www.instagram.com/p/CpmU__ONXUd/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.79 *Standardized Precipitation Index*



Source: Shared by Dohi Tarım, October 11, 2023, Retrieved from https://www.facebook.com/photo/?fbid=687107536773057&set=ecnf.100064214497103.

Figure C.80 *Meat Consumption Causes More Greenhouse Gas Emissions*



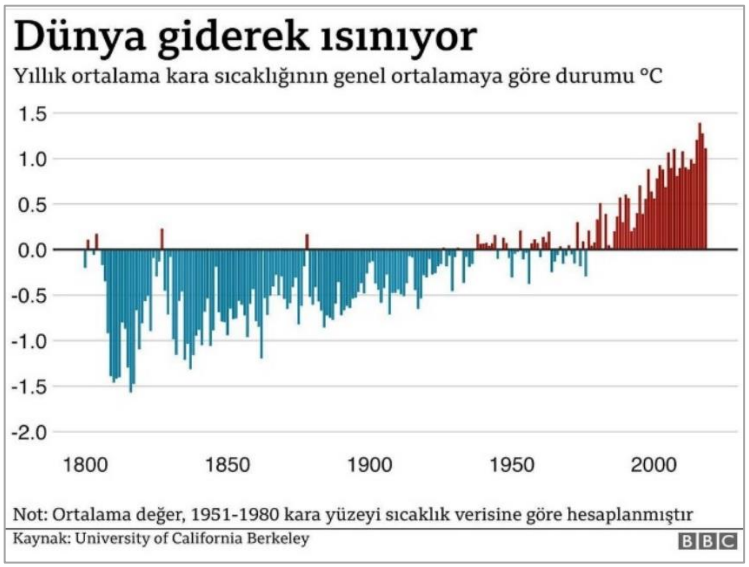
Source: BBC Turkce, July 21, 2023, Retrieved from https://www.bbc.com/turkce/articles/c99xgedzp8no.

Figure C.81 *Negative Effects of Consuming Too Much Meat*



Source: BBC Turkce, July 21, 2023, Retrieved from https://www.bbc.com/turkce/articles/c99xgedzp8no.

Figure C.82 *The World Is Getting Warmer*



Source: BBC Turkce, August 9, 2021, Retrieved from https://www.bbc.com/turkce/haberler-dunya-58143895.

Figure C.83 *17 thousand Species Are in Danger*



Source: TRT Haber, October 4, 2023, Retrieved from https://www.trthaber.com/infografik/17-bin-tur-tehlikede-125.html.

Figure C.84 *How Close Is the World to the 1.5 Degree Global Warming Limit*



Source: TRT Haber, September 22, 2023, Retrieved from https://www.trthaber.com/infografik/dunya-15-derecelik-kuresel-isinma-sinirini-asma-yolunda-92.html.

Figure C.85 *Climate Crisis in Developed Countries*



Source: TRT Haber, 2023, reshared in 2024 Retrieved from https://www.trthaber.com/haber/dunya/gelismis-ulkelerin-iklim-krizi-verilen-sozler-tutulmadi-797421.html.

Figure C.86 *Sea Water Temperature in Turkey Are Rising*



Source: TRT Haber, August 7, 2023, Retrieved from https://www.trthaber.com/infografik/turkiyenin-deniz-suyu-sicakliklarinda-2-derecelik-artis-var-42.html.

Figure C.87 *Record Temperature on July 26*



Source: TRT Haber, 2023, reshared, July 27, 2023, Retrieved from https://www.instagram.com/p/CvNZVOzrGjC/?utm_source=ig_web_copy_link.

Figure C.88 *Do You Take Your Shopping Bag With You to the Market*



Source: TRT Haber, June 1, 2023, Retrieved from https://www.trthaber.com/haber/dunya/plastik-kirliligini-onleyen-anlasma-yapilabilecek-mi-771656.html.

Figure C.89 *Leading Roles in Plastic Pollution in Oceans and Rivers*



Source: TRT Haber, June 1, 2023, Retrieved from https://www.trthaber.com/haber/dunya/plastik-kirliligini-onleyen-anlasma-yapilabilecek-mi-771656.html.

Figure C.90 *The Second Driest Winter in the Last 63 Years*



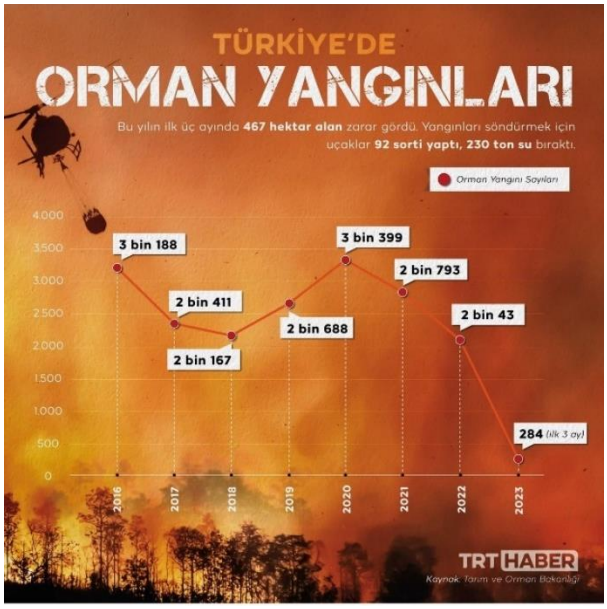
Source: TRT Haber, May 9, 2023, Retrieved from https://www.trthaber.com/haber/turkiye/son-63-yilin-en-yagissiz-ikinci-kisi-765880.html.

Figure C.91 *Zero Waste Day*



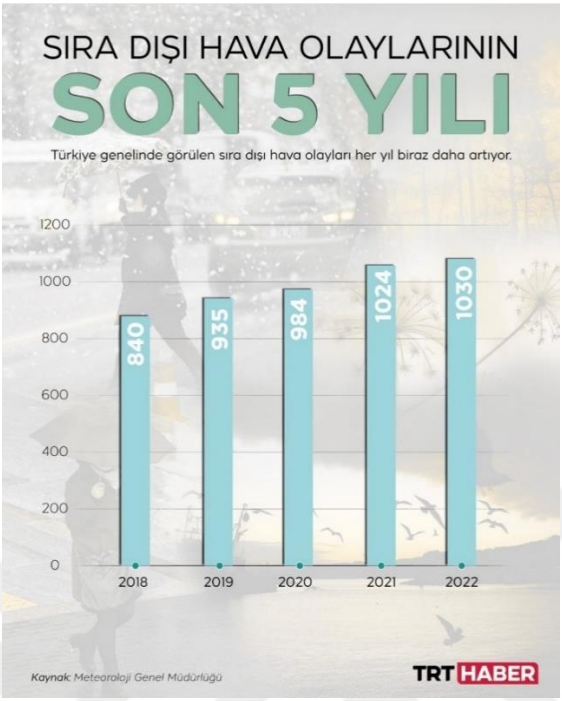
Source: TRT Haber, March 30, 2023, Retrieved from https://www.trthaber.com/haber/gundem/emine-erdogan-bmde-sifir-atik-ozel-oturumuna-katildi-757205.html.

Figure C.92 *Wildfires in Turkey*



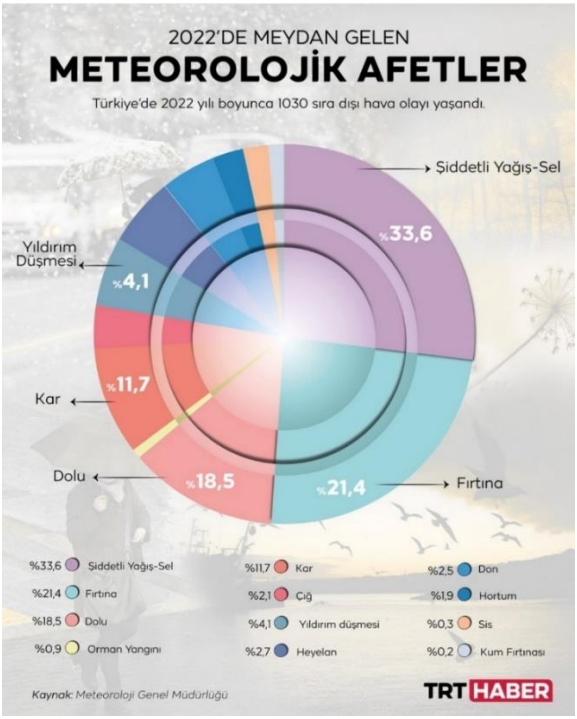
Source: TRT Haber, March 30, 2023, Retrieved from https://www.trthaber.com/haber/yasam/orman-yanginlari-icin-filo-buyuyor-756817.html.

Figure C.93 *The Last 5 Years of Extreme Weather Events*



Source: TRT Haber, March 14, 2023, Retrieved from https://www.trthaber.com/haber/yasam/2022de-bin-30-sira-disi-hava-olayi-yasandi-752843.html.

Figure C.94 *Meteorological Disaster in 2022*



Source: TRT Haber, March 14, 2023, Retrieved from https://www.trthaber.com/haber/yasam/2022de-bin-30-sira-disi-hava-olayi-yasandi-752843.html.

Figure C.95 *False Spring Delusion of Bees*



Source: TRT Haber, February 1, 2023, Retrieved from https://www.trthaber.com/haber/yasam/arilar-yalanci-bahara-aldandi-bal-uretiminde-dusus-bekleniyor-742554.html.

Figure C.96 *How Much Water Is Used in Production*



Source: TRT Haber, January 18, 2023, Retrieved from https://www.trthaber.com/haber/infografik/urunlerin-uretiminde-ne-kadar-su-harcaniyor-739299.html.

Figure C.97 *Reservoirs of Istanbul at a Dangerous Level*



Source: TRT Haber, January 7, 2023, Retrieved from https://www.trthaber.com/haber/infografik/istanbulda-kuraklik-alarmi-barajlar-kritik-seviyede-736398.html.

Figure C.98 *Annual Rainfall Amounts Measured in Dams*



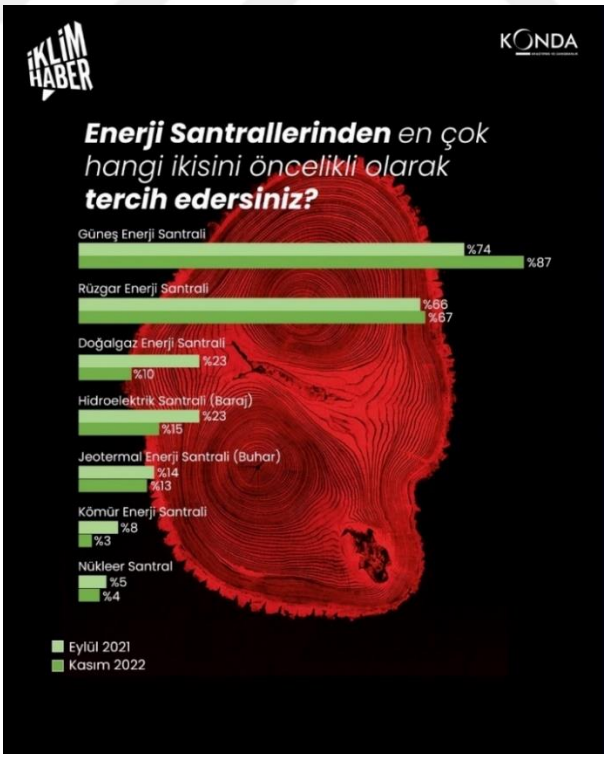
Source: TRT Haber, January 7, 2023, Retrieved from https://www.trthaber.com/haber/infografik/istanbulda-kuraklik-alarmi-barajlar-kritik-seviyede-736398.html.

Figure C.99 *Results of Packaging and Packaging Waste Released in 2020*



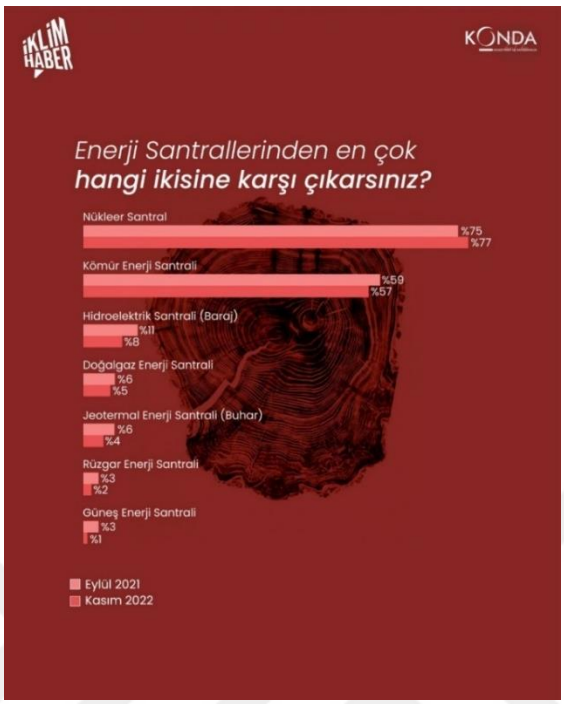
Source: TRT Haber, October 11, 2022, Retrieved from https://www.trthaber.com/haber/infografik/fazla-mi-paketliyoruz-714908.html.

Figure C.100 *Which Two Power Plants Do You Prefer the Most*



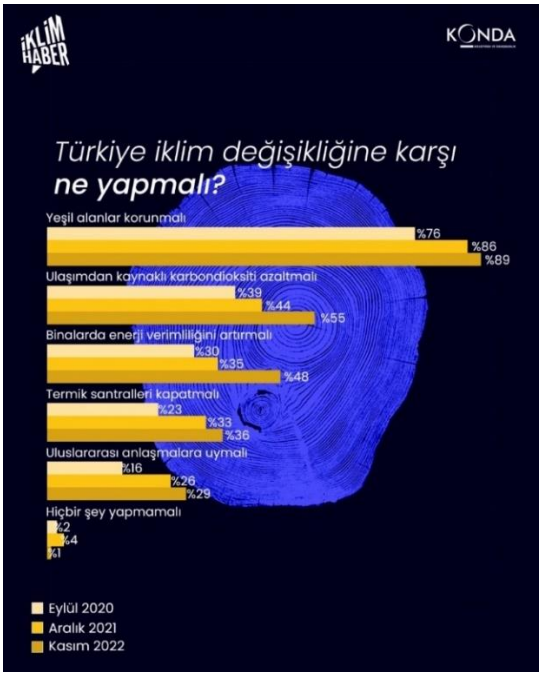
Source: İklim Haber, May 9, 2023, Retrieved from https://www.instagram.com/p/CsAvTB6tdVv/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.101 *Which Two Power Plants Do You Oppose the Most*



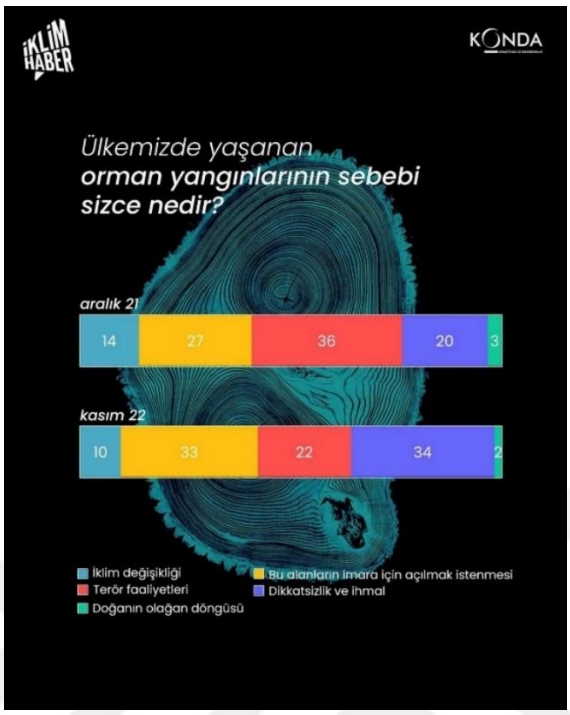
Source: İklim Haber, May 8, 2023, Retrieved from https://www.instagram.com/p/Cr-Kf_lPBVZ/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.102 *What Should Turkey Do Against Climate Change*



Source: İklim Haber, May 7, 2023, Retrieved from https://www.instagram.com/p/Cr7ltJeJv4J/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.103 *What Do You Think Is the Cause of Wildfires in Our Country*



Source: İklim Haber, May 4, 2023, Retrieved from https://www.instagram.com/p/Cr0Fl0ysRdS/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

Figure C.104 *Carbon Footprint of Food*



Source: Gıda Danışmanım, May 2, 2021, Retrieved from https://www.instagram.com/p/COXKX4mnmy9/?utm_source=ig_web_copy_link&igsh=MzRlODBiNWFlZA==.

APPENDIX D. SURVEY STRUCTURE AND DESIGN

Anket Başlığı:
İklim Değişikliği Bilgi Görselleştirme Ölçütlerinin Değerlendirilmesi ve Geçerlemesi
Giriş (Anket Açıklaması)
Değerli Katılımcı,
Bu anket, Özyeğin Üniversitesi Tasarım, Teknoloji ve Toplum Doktora Programı kapsamında "A Conceptual Framework of Information Visualization Measures: Identifying Key Evaluation Criteria for Climate Change Visuals" (Bilgi Görselleştirme Ölçütlerinin Kavramsal Çerçevesi: İklim Değişikliği Görselleri için Temel Değerlendirme Kriterlerinin Belirlenmesi) başlıklı tez çalışması altında iklim değişikliği bilgi görselleştirme ölçütlerinin üç temel iletişim hedefiyle ilişkisini değerlendirmek için hazırlanmıştır.
Anketin amacı, hedefler çerçevesinde öne çıkan ölçütleri belirlemek, her bir ölçütün iklim değişikliği iletişiminde hangi hedefe daha fazla katkı sağladığını anlamak ve çerçeveyi bilimsel olarak güçlendirmektir.
Anket üç ana bölümden oluşmaktadır ve yaklaşık 15 dakika sürecektir. Yanıtlarınız anonim kalacak ve sadece araştırma amacıyla kullanılacaktır. Anket hakkında soru ve görüşlerinizi ……... e-posta adresine iletebilirsiniz.
NOT: Mobil telefonlarda anketi yanıtlamak için telefonu yan çeviriniz.

Bölüm 1: Katılımcı Bilgileri (Demografi ve Uzmanlık Alanı)
Soru 1: Temel uzmanlık alanınız nedir?
☐ Grafik Tasarım
☐ Veri Görselleştirme
☐ İklim İletişimi
☐ Gazetecilik / Medya
☐ Çevre Bilimleri
☐ Sosyal Bilimler
☐ Diğer (Lütfen belirtiniz): _____

Soru 2: Kaç yıldır bu alanda çalışıyorsunuz?
☐ 0-2 yıl
☐ 3-5 yıl
☐ 6-10 yıl
☐ 11+ yıl

Soru 3: Daha önce iklim değişikliği ile ilgili veri görselleştirmeleri üzerinde çalıştınız mı?
☐ Evet
☐ Hayır
☐ Diğer……..

Bölüm 2: Bilgi Görselleştirme Ölçütlerinin Değerlendirilmesi
Bu bölümde bilgi görselleştirme ölçütlerinin üç temel iletişim hedefiyle ilişkisi değerlendirilecektir.

Hedef 1: Doğru Bilgiyle Güven Sağlama
İklim değişikliği görselleştirmelerinin güvenilir bilimsel bilgilere dayanarak oluşturulması ve yanıltıcı bilgileri önlemesi gerekmektedir.

Aşağıda**, iklim değişikliği bilgi görselleştirmelerinin etkinliğini belirleyen ölçütler** listelenmiştir. 'Hedef 1: Doğru Bilgiyle Güven Sağlama' için aşağıdaki ölçütler sizce ne oranda önemlidir? Lütfen 1 ile 5 arasında değerlendiriniz.

Ölçüt	**Önemli Değil (1)**	**Az Önemli (2)**	**Orta Derecede Önemli (3)**	**Önemli (4)**	**Çok Önemli (5)**
Netlik (Verilen bilginin karmaşadan uzak/ açık olması)	☐	☐	☐	☐	☐
İnanırlık (Bilgi ve kaynağın itibarlı olması)	☐	☐	☐	☐	☐
İlgi Çekicilik (Dikkat çekici ve ilgi uyandırıcı olması)	☐	☐	☐	☐	☐
Merak Uyandrma (konuya yönelik merakı teşvik etme)	☐	☐	☐	☐	☐
Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)	☐	☐	☐	☐	☐
Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)	☐	☐	☐	☐	☐
Olumlu olma (konuya olumlu açıdan yaklaşma)	☐	☐	☐	☐	☐
Aydınlatıcılık (Bilglendirme, eğitme, konuyu anlaşılır kılma)	☐	☐	☐	☐	☐
Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)	☐	☐	☐	☐	☐
Kişiselleştirme (Hedef kitle için anlamlı ve ilgili olması)	☐	☐	☐	☐	☐
Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)	☐	☐	☐	☐	☐
Harekete Geçirilebilirlik (İklim değişikliği konusunda eyleme geçmeye teşvik etmesi)	☐	☐	☐	☐	☐

Hedef 1: Doğru Bilgiyle Güven Sağlama
İklim değişikliği görselleştirmelerinin güvenilir bilimsel bilgilere dayanarak oluşturulması ve yanıltıcı bilgileri önlemesi gerekmektedir.

Hedef 1 için <u>olmazsa olmaz</u> ölçütler hangileridir. Lütfen en fazla 5 seçenek işaretleyin.
☐ Netlik (verilen bilginin karmaşadan uzak/açık olması)
☐ İnanırlık (bilgi ve kaynağın itibarlı olması)
☐ İlgi Çekicilik (dikkat çekici ve ilgi uyandırıcı olması)
☐ Merak Uyandırma (konuya yönelik merakı teşvik etme)

☐ Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)
☐ Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)
☐ Olumlu olma (konuya olumlu açıdan yaklaşma)
☐ Aydınlatıcı olma (bilglendirme, eğitme, konuyu anlaşılır kılma)
☐ Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)
☐ Kişiselleştirme (hedef kitle için anlamlı ve ilgili olması)
☐ Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)
☐ Harekete geçirilebilme (iklim değişikliği konusunda eyleme geçmeye teşvik etmesi)

Açık uçlu soru:
Bu hedefi destekleyen ek ölçütler olduğunu düşünüyor musunuz? Ek ölçütler olduğunu düşünüyorsanız lütfen belirtin.

Hedef 2: Paydaşlarla Açık, Kapsayıcı ve Çözüm Odaklı İletişim Kurma
Bu hedef, iklim değişikliği görselleştirmelerinin paydaşların ilgisini çekmesini, onları bilgiye dahil etmesini ve çözümler sunmasını amaçlar.

'Hedef 2: Paydaşlarla Açık, Kapsayıcı ve Çözüm Odaklı İletişim Kurma' için aşağıdaki ölçütler sizce ne oranda önemlidir? Lütfen 1 ile 5 arasında değerlendiriniz.

Ölçüt	Önemli Değil (1)	Az Önemli (2)	Orta Derecede Önemli (3)	Önemli (4)	Çok Önemli (5)
Netlik (Verilen bilginin karmaşadan uzak/ açık olması)	☐	☐	☐	☐	☐
İnanırlık (Bilgi ve kaynağın itibarlı olması)	☐	☐	☐	☐	☐
İlgi Çekicilik (Dikkat çekici ve ilgi uyandırıcı olması)	☐	☐	☐	☐	☐
Merak Uyandrma (konuya yönelik merakı teşvik etme)	☐	☐	☐	☐	☐
Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)	☐	☐	☐	☐	☐
Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)	☐	☐	☐	☐	☐
Olumlu olma (konuya olumlu açıdan yaklaşma)	☐	☐	☐	☐	☐
Aydınlatıcılık (Bilglendirme, eğitme, konuyu anlaşılır kılma)	☐	☐	☐	☐	☐
Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)	☐	☐	☐	☐	☐
Kişiselleştirme (Hedef kitle için anlamlı ve ilgili olması)	☐	☐	☐	☐	☐
Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)	☐	☐	☐	☐	☐
Harekete Geçirilebilirlik (İklim değişikliği konusunda eyleme geçmeye teşvik etmesi)	☐	☐	☐	☐	☐

Hedef 2: Paydaşlarla Açık, Kapsayıcı ve Çözüm Odaklı İletişim Kurma

Bu hedef, iklim değişikliği görselleştirmelerinin paydaşların ilgisini çekmesini, onları bilgiye dahil etmesini ve çözümler sunmasını amaçlar.
Hedef 2 için olmazsa olmaz ölçütler hangileridir. Lütfen en fazla 5 seçenek işaretleyin.
☐ Netlik (verilen bilginin karmaşadan uzak/açık olması)
☐ İnanırlık (bilgi ve kaynağın itibarlı olması)
☐ İlgi Çekicilik (dikkat çekici ve ilgi uyandırıcı olması)
☐ Merak Uyandırma (konuya yönelik merakı teşvik etme)
☐ Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)
☐ Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)
☐ Olumlu olma (konuya olumlu açıdan yaklaşma)
☐ Aydınlatıcı olma (bilglendirme, eğitme, konuyu anlaşılır kılma)
☐ Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)
☐ Kişiselleştirme (hedef kitle için anlamlı ve ilgili olması)
☐ Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)
☐ Harekete geçirilebilme (iklim değişikliği konusunda eyleme geçmeye teşvik etmesi)

Açık uçlu soru:
Bu hedefi destekleyen ek ölçütler olduğunu düşünüyor musunuz? Ek ölçütler olduğunu düşünüyorsanız lütfen belirtin.

Hedef 3: Acil Önem Atfederek ve Umut Vererek Katılım Sağlama
Bu hedef, iklim değişikliği görselleştirmelerinin sadece bilgi vermekle kalmayıp, çeşitli eylemlere katılımı teşvik etmesini içerir.

'Hedef 3: Acil Önem Atfederek ve Umut Vererek Katılım Sağlama' için aşağıdaki ölçütler sizce ne oranda önemlidir? Lütfen 1 ile 5 arasında değerlendiriniz.

Ölçüt	**Önemli Değil (1)**	**Az Önemli (2)**	**Orta Derecede Önemli (3)**	**Önemli (4)**	**Çok Önemli (5)**
Netlik (Verilen bilginin karmaşadan uzak/ açık olması)	☐	☐	☐	☐	☐
İnanırlık (Bilgi ve kaynağın itibarlı olması)	☐	☐	☐	☐	☐
İlgi Çekicilik (Dikkat çekici ve ilgi uyandırıcı olması)	☐	☐	☐	☐	☐
Merak Uyandrma (konuya yönelik merakı teşvik etme)	☐	☐	☐	☐	☐
Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)	☐	☐	☐	☐	☐
Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)	☐	☐	☐	☐	☐
Olumlu olma (konuya olumlu açıdan yaklaşma)	☐	☐	☐	☐	☐
Aydınlatıcılık (Bilglendirme, eğitme, konuyu anlaşılır kılma)	☐	☐	☐	☐	☐

Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)	☐	☐	☐	☐	☐
Kişiselleştirme (Hedef kitle için anlamlı ve ilgili olması)	☐	☐	☐	☐	☐
Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)	☐	☐	☐	☐	☐
Harekete Geçirilebilirlik (İklim değişikliği konusunda eyleme geçmeye teşvik etmesi)	☐	☐	☐	☐	☐

Hedef 3: Acil Önem Atfederek ve Umut Besleyerek Katılım Sağlama
Bu hedef, iklim değişikliği görselleştirmelerinin sadece bilgi vermekle kalmayıp, çeşitli eylemlere katılımı teşvik etmeyi içerir.

Hedef 3 için olmazsa olmaz ölçütler hangileridir. Lütfen en fazla 5 seçenek işaretleyin.
☐ Netlik (verilen bilginin karmaşadan uzak/açık olması)
☐ İnanırlık (bilgi ve kaynağın itibarlı olması)
☐ İlgi Çekicilik (dikkat çekici ve ilgi uyandırıcı olması)
☐ Merak Uyandırma (konuya yönelik merakı teşvik etme)
☐ Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)
☐ Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)
☐ Olumlu olma (konuya olumlu açıdan yaklaşma)
☐ Aydınlatıcı olma (bilglendirme, eğitme, konuyu anlaşılır kılma)
☐ Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)
☐ Kişiselleştirme (hedef kitle için anlamlı ve ilgili olması)
☐ Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)
☐ Harekete geçirilebilme (iklim değişikliği konusunda eyleme geçmeye teşvik etmesi)

Açık uçlu soru:
Bu hedefi destekleyen ek ölçütler olduğunu düşünüyor musunuz? Ek ölçütler olduğunu düşünüyorsanız lütfen belirtin.

Bölüm 3: Uzman Görüşü ve Açık Uçlu Sorular

1. **Bu çerçevede eksik olduğunu düşündüğünüz herhangi bir ölçüt var mı?**
    - ☐ Hayır, çerçeve tüm önemli ölçütleri kapsıyor.
    - ☐ Diğer _____
2. **Sizce, etkili iklim değişikliği görselleştirmeleri için en önemli üç ölçüt hangileridir?**

☐ Netlik (verilen bilginin karmaşadan uzak/açık olması)
☐ İnanırlık (bilgi ve kaynağın itibarlı olması)
☐ İlgi Çekicilik (dikkat çekici ve ilgi uyandırıcı olması)
☐ Merak Uyandırma (konuya yönelik merakı teşvik etme)
☐ Duygu Uyandırma (hedef kitlede konuyla ilgili duygu yaratma)

☐ Hikayeleştirme (bilginin/mesajın bir anlatı şeklinde sunumu)
☐ Olumlu olma (konuya olumlu açıdan yaklaşma)
☐ Aydınlatıcı olma (bilglendirme, eğitme, konuyu anlaşılır kılma)
☐ Önemli noktayı vurgulama (bilgi veya mesajın önemli noktasını belirginleştirme)
☐ Kişiselleştirme (hedef kitle için anlamlı ve ilgili olması)
☐ Yerelleştirme (bilginin/mesajın bölgesel bağlama uygunluğu)
☐ Harekete geçirilebilme (iklim değişikliği konusunda eyleme geçmeye teşvik etmesi)

Kapanış:
Katılımınız ve değerli görüşleriniz için teşekkür ederiz! Yanıtlarınız, **iklim değişikliği görselleştirme çerçevesinin güçlendirilmesine** katkı sağlayacaktır.
Eğer çalışmanın sonuçlarını almak isterseniz, lütfen e-posta adresinizi yazınız (isteğe bağlı): **[Metin Kutusu]**

The Survey (English Translation)

Survey Title
Evaluation and Validation of Climate Change Information Visualization Measures
Introduction (Survey Description)
Dear Participant,
This survey is part of the doctoral research project titled "A Conceptual Framework of Information Visualization Measures: Identifying Key Evaluation Criteria for Climate Change Visuals" conducted under the Design, Technology and Society PhD Program at Özyeğin University. Its purpose is to evaluate how a set of information visualization measures relate to three core communication goals in the context of climate change.
The aim of the survey is to identify which measures are most strongly associated with each goal, understand how they contribute to effective communication, and strengthen the proposed framework through empirical input.
The survey consists of three main sections and will take approximately 15 minutes to complete. Your responses will remain anonymous and will be used only for academic purposes. For questions or feedback, you may contact …….

NOTE: If you are using a mobile phone, please rotate your device for optimal survey experience.

Section 1: Participant Information (Demographics and Expertise)
Question 1: What is your primary field of expertise?
☐ Graphic Design
☐ Data Visualization
☐ Climate Communication
☐ Journalism / Media
☐ Environmental Sciences
☐ Social Sciences
☐ Other (Please specify): _____

Question 2: How many years of experience do you have in your field?
☐ 0-2 years
☐ 3-5 years
☐ 6-10 years
☐ 11+ years

Question 3: Have you previously worked on visualizing climate-related data?
☐ Yes
☐ No
☐ Other……..

Section 2: Evaluation of Information Visualization Measures
In this section, you will be asked to evaluate the relevance of each visualization measure to the **three key communication goals** identified for climate change communication.

Goal 1: Building Trust Through Reliable Information
Climate change visualizations should be based on reliable scientific information and should avoid spreading misinformation.

Please rate the importance of each measure below in achieving Goal 1 using a 1 to 5 scale:

Measure	Not Important (1)	Slightly Important (2)	Moderately Important (3)	Important (4)	Very Important (5)
Clarity (information is clear and unambiguous)	☐	☐	☐	☐	☐
Credibility (source and content are trustworthy)	☐	☐	☐	☐	☐
Engagement (visually compelling and attention-grabbing)	☐	☐	☐	☐	☐
Evoking Curiosity (sparks interest in the topic)	☐	☐	☐	☐	☐
Evoking Emotions (generates emotional response)	☐	☐	☐	☐	☐
Storytelling (information presented in a narrative form)	☐	☐	☐	☐	☐
Positivity (conveys the topic with a positive outlook)	☐	☐	☐	☐	☐
Enlightening (educational, illuminating, easy to grasp)	☐	☐	☐	☐	☐
Saliency (emphasizes core message)	☐	☐	☐	☐	☐
Personalization (relevant and meaningful to audience)	☐	☐	☐	☐	☐
Localization (adapted to local/regional context)	☐	☐	☐	☐	☐
Actionability (encourages action on climate issues)	☐	☐	☐	☐	☐

Goal 1: Building Trust Through Reliable Information
Climate change visualizations should be based on reliable scientific information and should avoid spreading misinformation.

For Goal 1, please select up to five measures that you consider <u>indispensable</u>:

☐ Clarity (information is clear and unambiguous)
☐ Credibility (source and content are trustworthy)
☐ Engagement (visually compelling and attention-grabbing)
☐ Evoking Curiosity (sparks interest in the topic)
☐ Evoking Emotions (generates emotional response)
☐ Storytelling (information presented in a narrative form)

☐ Positivity (conveys the topic with a positive outlook)
☐ Enlightening (educational, illuminating, easy to grasp)
☐ Saliency (emphasizes core message)
☐ Personalization (relevant and meaningful to audience)
☐ Localization (adapted to local/regional context)
☐ Actionability (encourages action on climate issues)

Open-ended Question:
Do you think there are any additional measures that support this goal? If yes, please specify.

Goal 2: Establishing Clear, Inclusive, and Solution-Oriented Communication with Stakeholders

This goal focuses on ensuring climate visualizations engage stakeholders, include diverse perspectives, and offer solutions.

Please rate the importance of each measure below in achieving Goal 2 using a 1 to 5 scale:

Measure	Not Important (1)	Slightly Important (2)	Moderately Important (3)	Important (4)	Very Important (5)
Clarity (information is clear and unambiguous)	☐	☐	☐	☐	☐
Credibility (source and content are trustworthy)	☐	☐	☐	☐	☐
Engagement (visually compelling and attention-grabbing)	☐	☐	☐	☐	☐
Evoking Curiosity (sparks interest in the topic)	☐	☐	☐	☐	☐
Evoking Emotions (generates emotional response)	☐	☐	☐	☐	☐
Storytelling (information presented in a narrative form)	☐	☐	☐	☐	☐
Positivity (conveys the topic with a positive outlook)	☐	☐	☐	☐	☐
Enlightening (educational, illuminating, easy to grasp)	☐	☐	☐	☐	☐
Saliency (emphasizes core message)	☐	☐	☐	☐	☐
Personalization (relevant and meaningful to audience)	☐	☐	☐	☐	☐
Localization (adapted to local/regional context)	☐	☐	☐	☐	☐

Actionability (encourages action on climate issues)	☐	☐	☐	☐	☐

Goal 2: Establishing Clear, Inclusive, and Solution-Oriented Communication with Stakeholders

This goal focuses on ensuring climate visualizations engage stakeholders, include diverse perspectives, and offer solutions.

For Goal 2, please select up to five measures that you consider indispensable:
☐ Clarity (information is clear and unambiguous)
☐ Credibility (source and content are trustworthy)
☐ Engagement (visually compelling and attention-grabbing)
☐ Evoking Curiosity (sparks interest in the topic)
☐ Evoking Emotions (generates emotional response)
☐ Storytelling (information presented in a narrative form)
☐ Positivity (conveys the topic with a positive outlook)
☐ Enlightening (educational, illuminating, easy to grasp)
☐ Saliency (emphasizes core message)
☐ Personalization (relevant and meaningful to audience)
☐ Localization (adapted to local/regional context)
☐ Actionability (encourages action on climate issues)

Open-ended Question:
Do you think there are any additional measures that support this goal? If yes, please specify.

Goal 3: Encouraging Action with a Sense of Urgency and Hope

This goal emphasizes not only informing the public but also motivating them to take climate action.

Please rate the importance of each measure below in achieving Goal 2 using a 1 to 5 scale:

Measure	Not Important (1)	Slightly Important (2)	Moderately Important (3)	Important (4)	Very Important (5)
Clarity (information is clear and unambiguous)	☐	☐	☐	☐	☐
Credibility (source and content are trustworthy)	☐	☐	☐	☐	☐
Engagement (visually compelling and attention-grabbing)	☐	☐	☐	☐	☐
Evoking Curiosity (sparks interest in the topic)	☐	☐	☐	☐	☐
Evoking Emotions (generates emotional response)	☐	☐	☐	☐	☐

Storytelling (information presented in a narrative form)	☐	☐	☐	☐	☐
Positivity (conveys the topic with a positive outlook)	☐	☐	☐	☐	☐
Enlightening (educational, illuminating, easy to grasp)	☐	☐	☐	☐	☐
Saliency (emphasizes core message)	☐	☐	☐	☐	☐
Personalization (relevant and meaningful to audience)	☐	☐	☐	☐	☐
Localization (adapted to local/regional context)	☐	☐	☐	☐	☐
Actionability (encourages action on climate issues)	☐	☐	☐	☐	☐

Goal 3: Encouraging Action with a Sense of Urgency and Hope
This goal emphasizes not only informing the public but also motivating them to take climate action.
For Goal 3, please select up to five measures that you consider indispensable:
☐ Clarity (information is clear and unambiguous)
☐ Credibility (source and content are trustworthy)
☐ Engagement (visually compelling and attention-grabbing)
☐ Evoking Curiosity (sparks interest in the topic)
☐ Evoking Emotions (generates emotional response)
☐ Storytelling (information presented in a narrative form)
☐ Positivity (conveys the topic with a positive outlook)
☐ Enlightening (educational, illuminating, easy to grasp)
☐ Saliency (emphasizes core message)
☐ Personalization (relevant and meaningful to audience)
☐ Localization (adapted to local/regional context)
☐ Actionability (encourages action on climate issues)

Open-ended Question:
Do you think there are any additional measures that support this goal? If yes, please specify.

Section 3: Expert Feedback & Open-Ended Questions

1. **Do you think any important measures are missing from this framework?**
   ☐ No, the framework includes all essential measures.
   ☐ Other (please explain): _____
2. **Which three measures do you believe are the most essential for effective climate . change visualizations? (Select up to three)**

☐ Clarity (information is clear and unambiguous)
☐ Credibility (source and content are trustworthy)
☐ Engagement (visually compelling and attention-grabbing)
☐ Evoking Curiosity (sparks interest in the topic)
☐ Evoking Emotions (generates emotional response)
☐ Storytelling (information presented in a narrative form)
☐ Positivity (conveys the topic with a positive outlook)
☐ Enlightening (educational, illuminating, easy to grasp)
☐ Saliency (emphasizes core message)
☐ Personalization (relevant and meaningful to audience)
☐ Localization (adapted to local/regional context)
☐ Actionability (encourages action on climate issues)

Closing Note:
Thank you for your time and valuable insights! Your responses will contribute significantly to strengthening the proposed framework for climate change visualizations. If you would like to receive the results of this study, please enter your email address below (optional):
[Text Box]

APPENDIX E. FIRST LEVEL OF CODES IN WORKSHOPS 1-5

Figure E.1 *Workshop 1 First Level Codes 1*

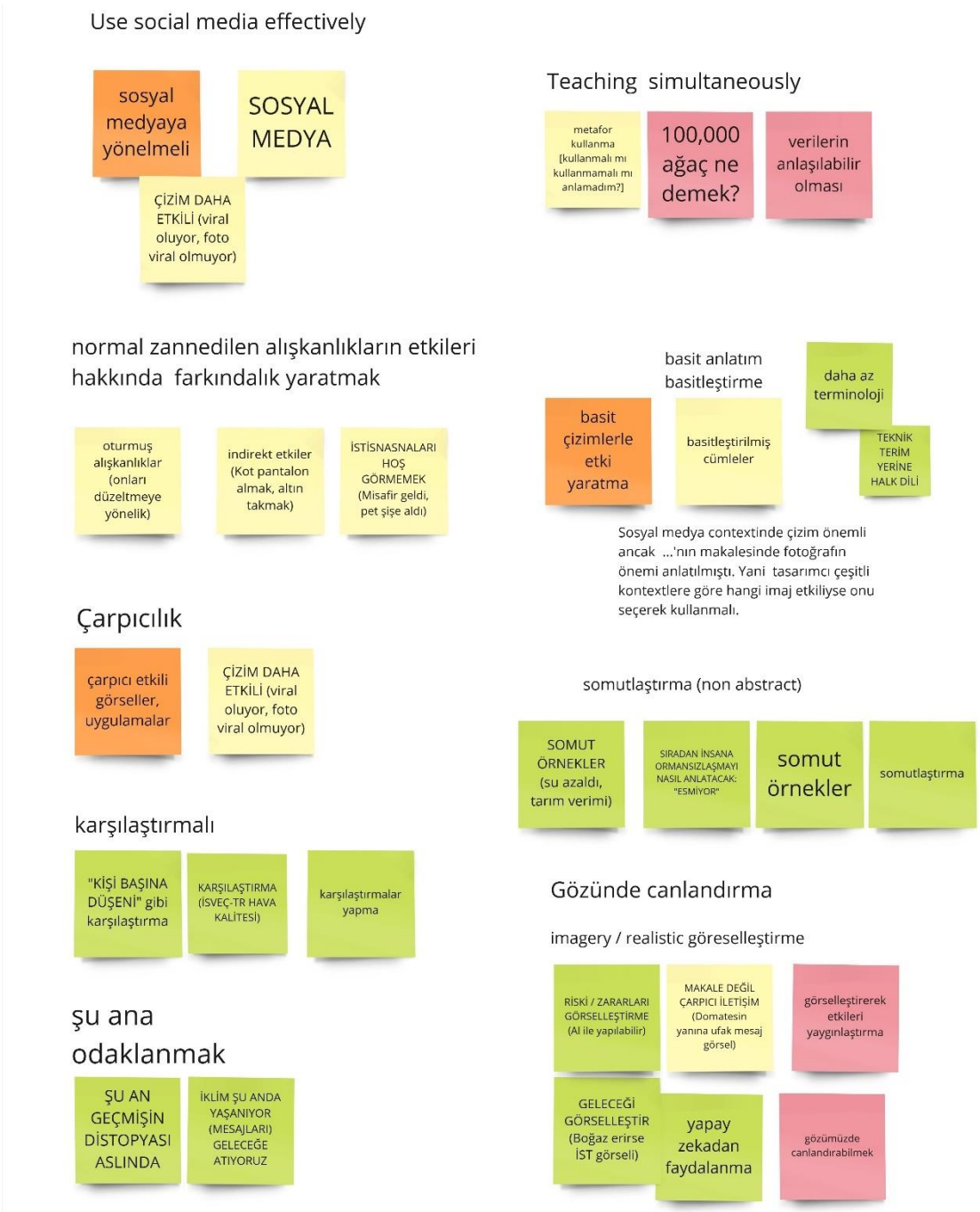


Figure E.2 *Workshop 1 First Level Codes 2*



Figure E.3 *Workshop 2 First Level Codes 1*

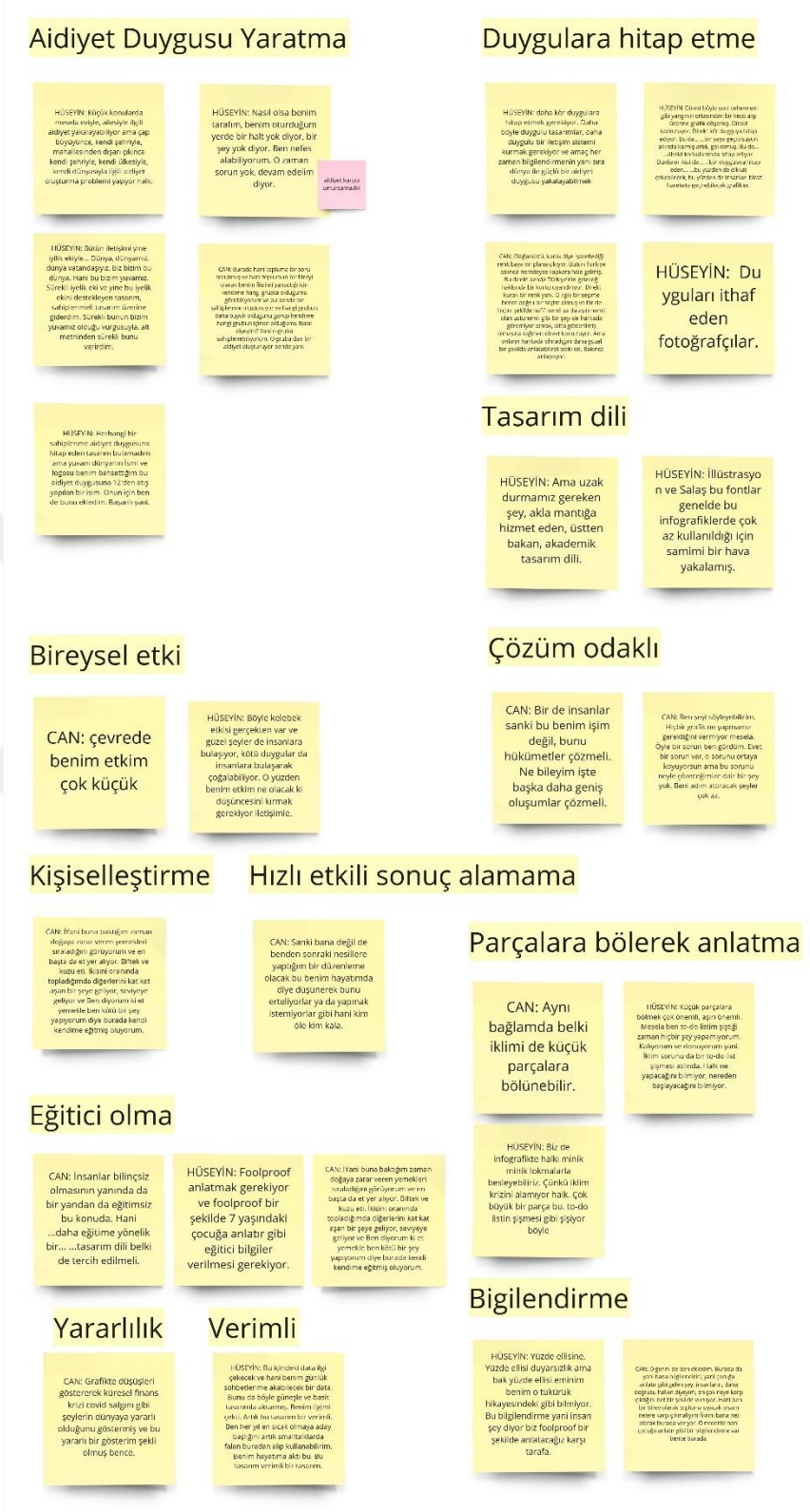


Figure E.4 *Workshop 2 First Level Codes 2*



Figure E.5 *Workshop 2 First Level Codes 3*



Figure E.6 *Workshop 2 First Level Codes 4*

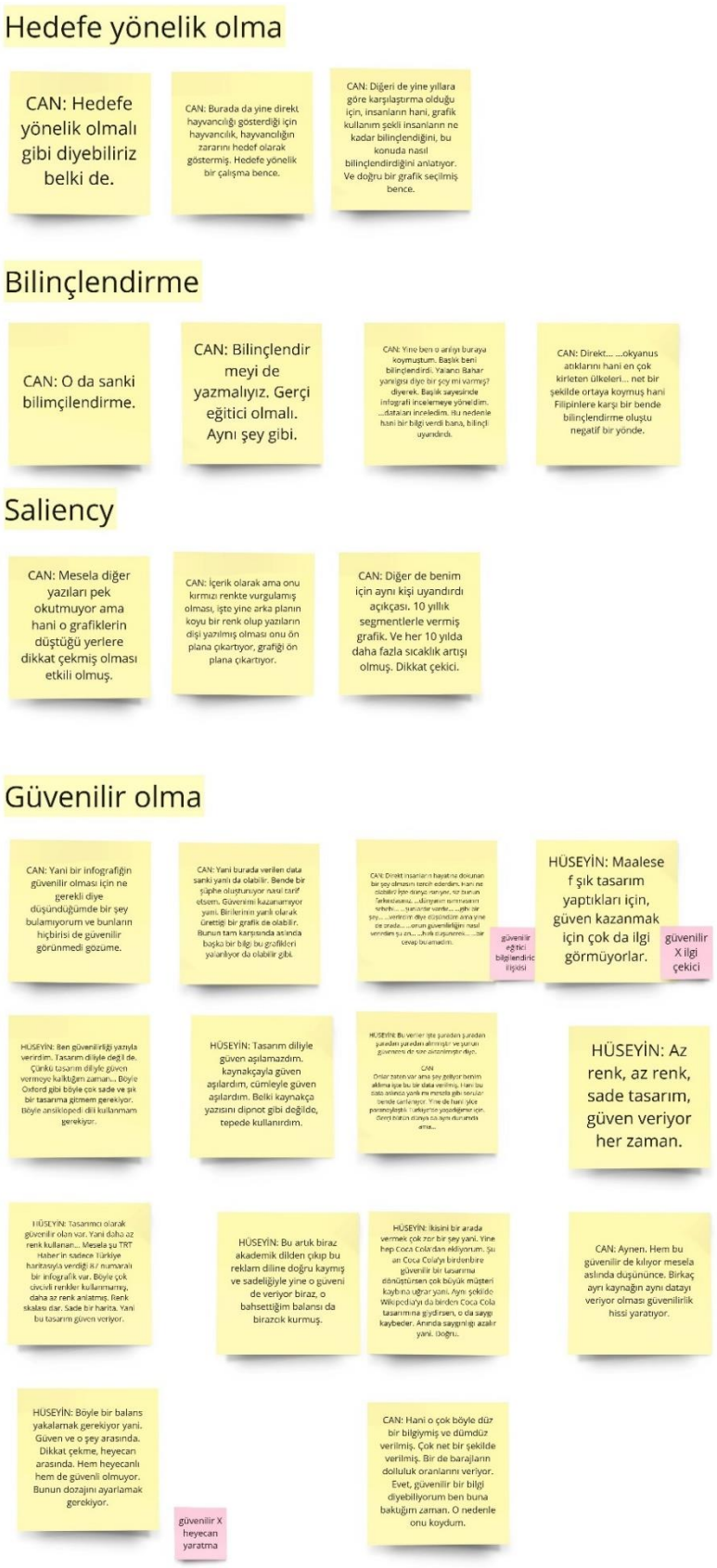


Figure E.7 *Workshop 2 First Level Codes 5*

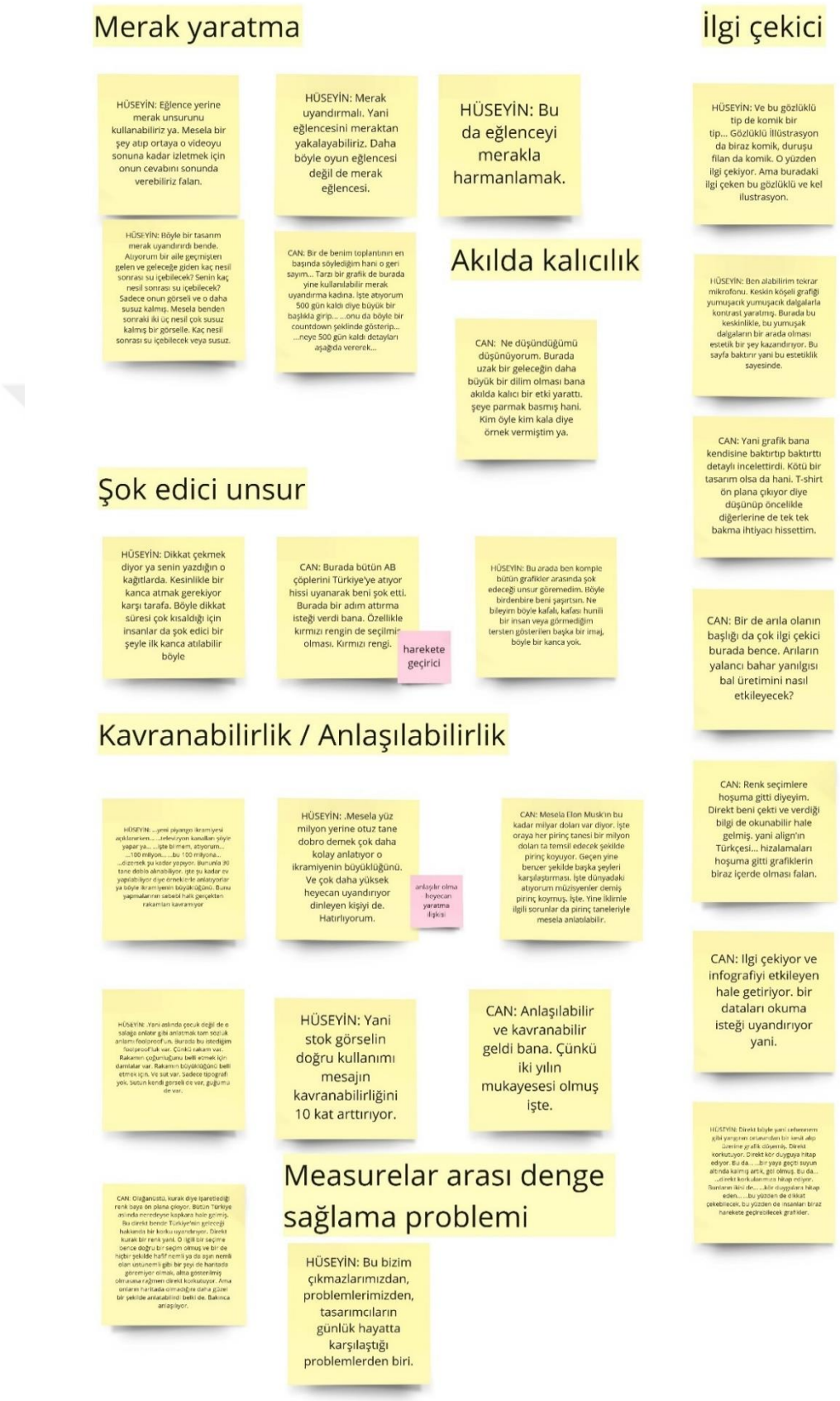


Figure E.8 *Workshop 3 First Level Codes 1*



Figure E.9 *Workshop 3 First Level Codes 2*





Figure E.10 *Workshop 3 First Level Codes 3*



Figure E.11 *Workshop 3 First Level Codes 4*



Figure E.12 *Workshop 3 First Level Codes 5*



Figure E.13 *Workshop 3 First Level Codes 6*



Figure E.14 *Workshop 4 First Level Codes 1*

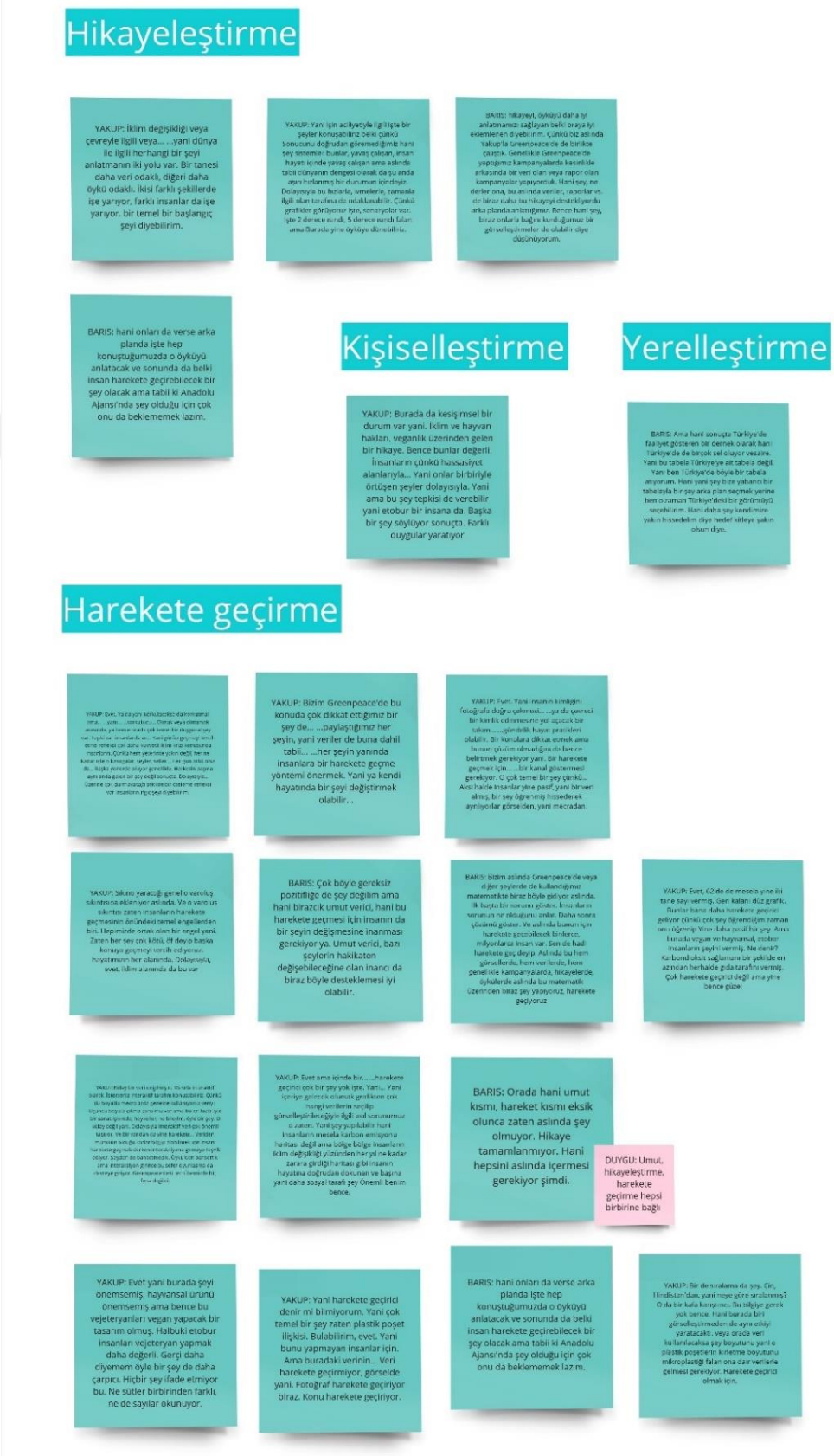


Figure E.15 *Workshop 4 First Level Codes 2*

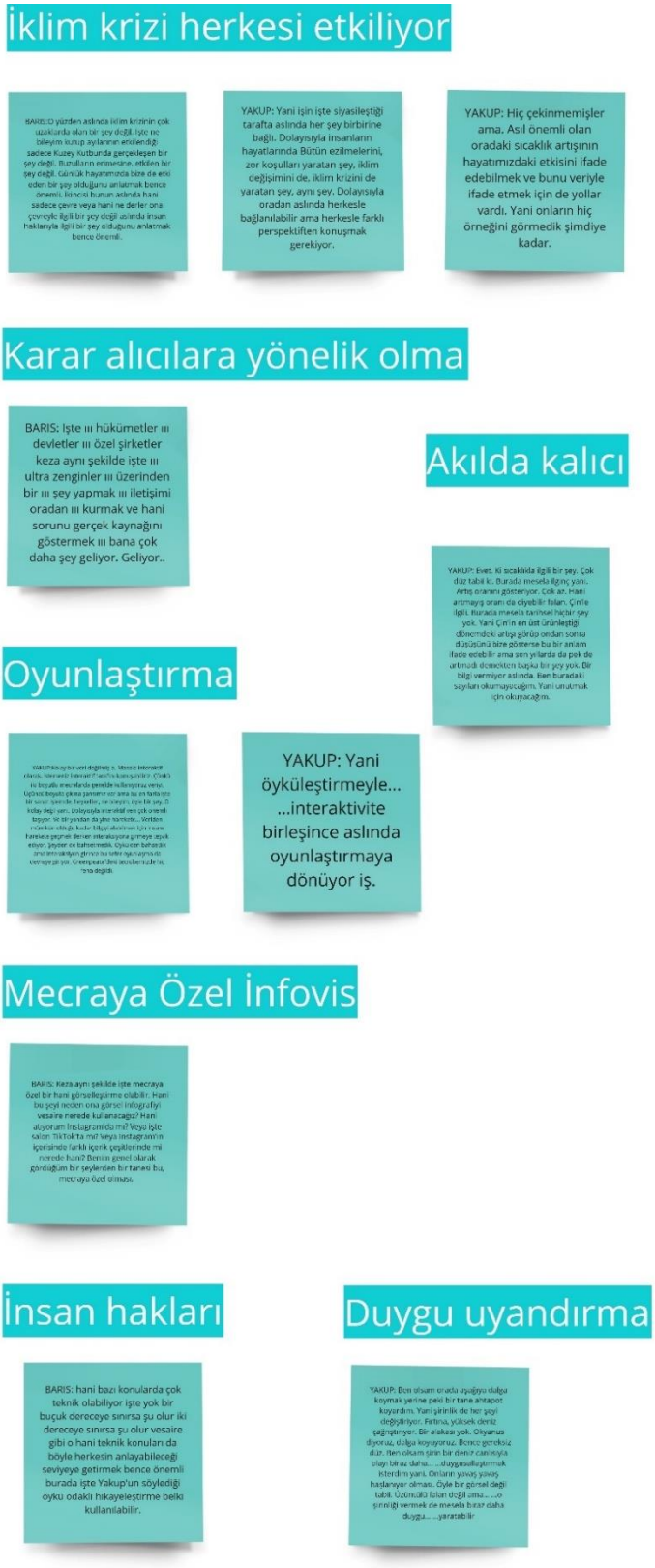


Figure E.16 *Workshop 4 First Level Codes 3*



Figure E.17 *Workshop 4 First Level Codes 4*

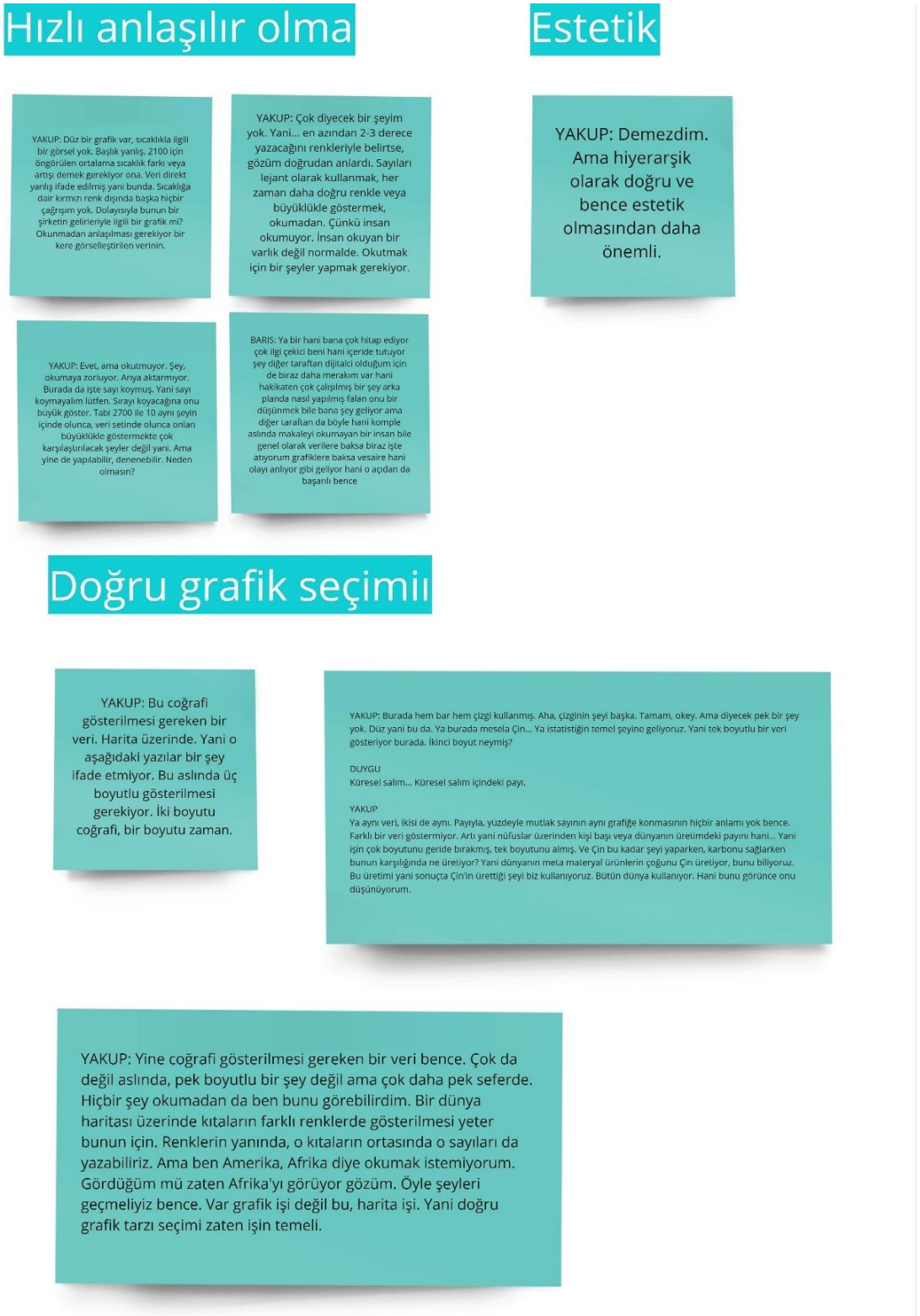


Figure E.18 *Workshop 4 First Level Codes 5*



Figure E.19 *Workshop 4 First Level Codes 6*

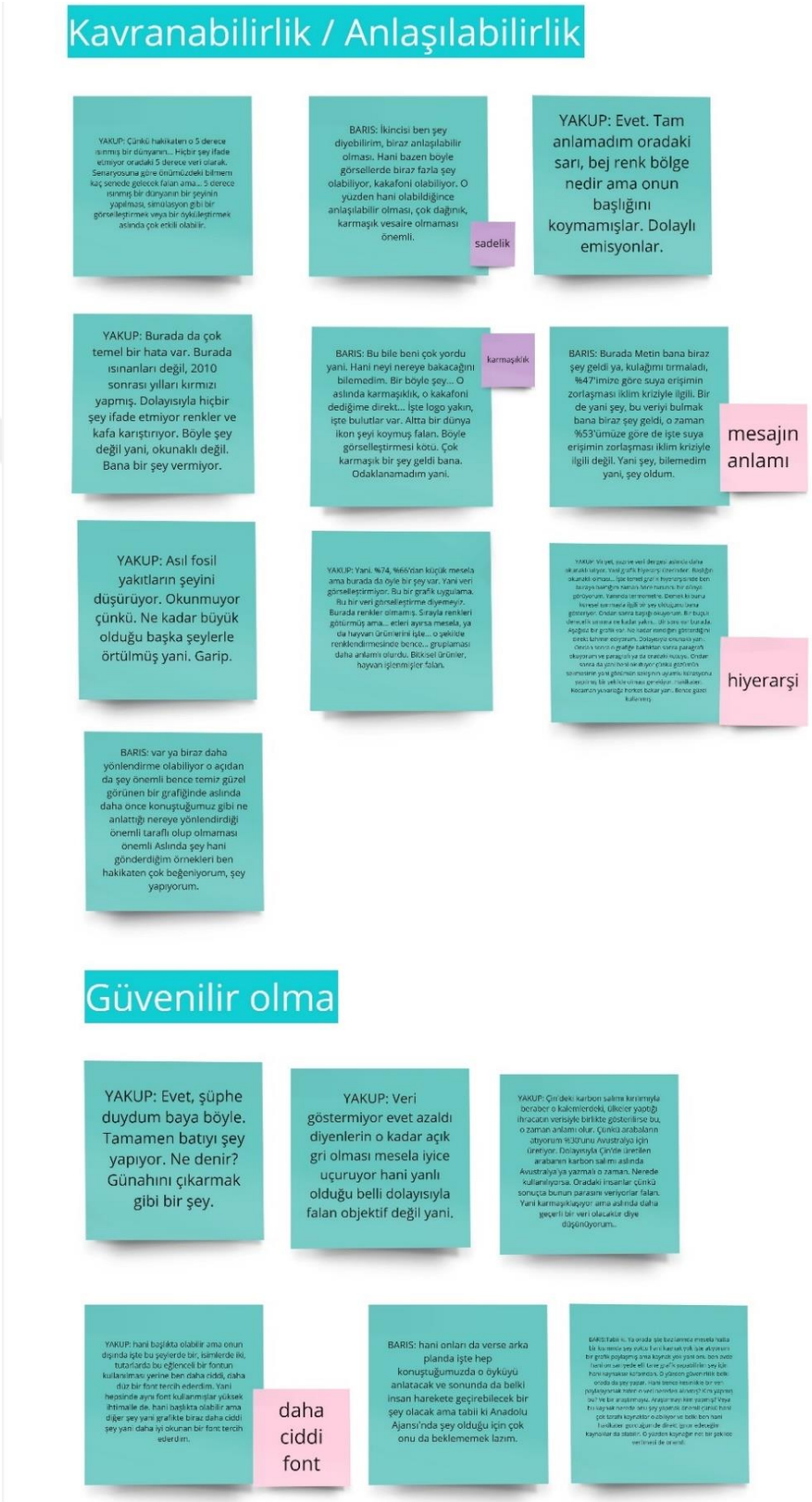


Figure E.20 *Workshop 5 First Level Codes 1*



Figure E.21 *Workshop 5 First Level Codes 2*



Figure E.22 *Workshop 5 First Level Codes 3*



Figure E.23 *Workshop 5 First Level Codes 4*



Figure E.24 *Workshop 5 First Level Codes 5*



Figure E.25 *Workshop 5 First Level Codes 6*



Figure E.26 *Workshop 5 First Level Codes 7*



APPENDIX F. GLOSSARY

Accuracy: The extent to which information presented in a visualization precisely reflects the actual data values or scientific findings, minimizing errors and misinterpretations.

Actionability: The degree to which a visualization enables or encourages viewers to take action or make decisions based on the information presented.

Aesthetics: The visual appeal or artistic quality of a visualization. This refers to how attractive, well-crafted, or pleasing the design is, including the use of color, layout, and style.

Audience Segmentation: The practice of dividing a broad audience into distinct groups based on characteristics like knowledge, attitudes, or demographic traits. In climate change communication, audience segmentation is used to tailor messages to specific groups.

Bar Chart: A common type of chart that displays data with rectangular bars, where the length (or height) of each bar is proportional to the value it represents. Each bar typically corresponds to a category, allowing easy comparison across categories. Bar charts are one of the most frequently used graphs in information visualization.

Chart: A broader category of visual representations used to organize, summarize, and illustrate data, including graphs, diagrams, and tables.

Chart-junk: Non-essential decorative visual elements in charts or graphs that add no informational value and potentially distract or confuse viewers.

Choropleth Map: A thematic map in which geographic areas (such as countries, regions, or districts) are shaded or colored according to a data variable's value in those areas. The shading is proportional to the magnitude of the variable.

Clarity: The quality of a visualization being easily readable and understandable. High clarity means the information is presented in a straightforward, unambiguous manner, free of unnecessary complexity.

Credibility: The perceived trustworthiness and reliability of the information presented in a visualization.

Data-ink Ratio: The proportion of ink (or pixels) used in a visualization that directly conveys essential data versus non-essential or decorative elements; high data-ink ratio is considered optimal.

Diagram: A simplified visual depiction used to explain structures, processes, or relationships, typically without a coordinate system (e.g., flowcharts, concept maps).
Eco-anxiety: Feelings of worry, fear, or distress related to environmental issues, particularly the effects and uncertainties surrounding climate change.

Efficiency: The effectiveness of a visualization in allowing users to quickly complete a specific task or understand data with minimal effort.

Engagement: The level of interest, involvement, and interaction that a visualization elicits from its audience. High engagement means viewers are not only paying attention but also mentally processing the information, and possibly interacting with it (if it's interactive), or reflecting on it afterward.

Enjoyment: The positive emotional experience viewers have while interacting with or viewing a visualization, contributing to sustained engagement.

Enlightening: The quality of a visualization that educates or illuminates the audience, providing new understanding or insight. An "enlightening" visual makes complex information easier to grasp – it might break down a complicated concept or reveal a pattern in data that wasn't obvious before.

Evoking Curiosity: The extent to which a visualization sparks interest and encourages the viewer to explore or ask questions.

Evoking Emotions: The effect a visualization has on the viewer's emotions – essentially, how successfully it provokes an emotional response. A climate visualization with strong emotional impact might inspire feelings such as concern, urgency, hope, or empathy.

Graph: A visual representation of quantitative data or relationships between variables, often plotted along axes within a coordinate system (e.g., line graphs, scatter plots).

Green PR: Public relations activities specifically aimed at promoting an organization's environmentally friendly practices, policies, or products to improve public perception.

Green Washing: A deceptive practice where an organization falsely promotes itself as environmentally friendly to improve public image without substantial environmental actions.

Heatmap: A graphical representation of data where values are depicted by color in a two-dimensional grid or map. Each cell in a heatmap corresponds to a combination of two variables (one for the cell's row, one for the column), and its color intensity or hue represents the data value for that pair.

Infographic: A visual representation that combines graphics, charts, and minimal text to present information clearly and quickly.

Information Visualization: The practice of converting data or abstract information into a visual form (such as charts, maps, or diagrams) that can be readily understood and analyzed. The goal of information visualization is to leverage our visual perception to make sense of complex data – by seeing patterns, trends, and outliers that might not be obvious from raw numbers.

Line Graph: A type of chart that displays data points connected by straight lines, typically to show trends over time or another continuous variable. The horizontal axis usually represents the progression (often time) and the vertical axis represents the quantity being measured.

Localization: Adapting information to a specific local context or emphasizing local details of a broader phenomenon. In terms of visualization, localization means presenting data in a way that is directly relevant to a particular location or audience segment.

Measure: Criteria or standards used to evaluate the effectiveness, quality, and impact of information visualizations.

Memorability: The likelihood that a viewer will remember the information or image from a visualization after some time has passed.

Personalization: Tailoring a visualization's content or experience to the specific viewer or a defined audience, making it more personally relevant.

Pictogram: A visualization type using symbolic pictures or icons to represent numerical data, making it easily comprehensible and engaging.

Pie Chart: A circular chart divided into slices, where each slice represents a part or percentage of a whole. The entire pie represents 100% of a dataset, and each slice's size (angle and area) correspond to the proportion of that category within the total.

Positivity: In communication, this refers to emphasizing positive messaging or optimistic elements. A visual with positivity might highlight solutions, improvements, or hopeful scenarios rather than focusing solely on negatives or threats.

Saliency: The prominence or emphasis given to the most important information in a visualization. A salient element is one that stands out immediately to the viewer.

Scatter Plot: A type of diagram that uses Cartesian coordinates to display values for two (or sometimes more) variables for a set of data. Each point on a scatter plot represents an individual data item with its position determined by its values on the horizontal (x) and vertical (y) axes.

Speed: The measure of how quickly a viewer can correctly interpret or extract essential information from a visualization.
Storytelling: The use of narrative elements and structure in presenting information, transforming raw data into a coherent story with a beginning, middle, and end or some narrative flow. In a visualization context, storytelling might involve guiding the viewer through the data in a logical sequence, often highlighting a problem and resolution or cause and effect.

Table: An organized arrangement of data in rows and columns, used to systematically display numeric or textual information for easy reference and comparison.

Two-Way Symmetric Model: A model of communication that emphasizes dialogue and mutual understanding between the communicator and the audience. Originating from public relations theory (specifically, Grunig's models of PR), the two-way symmetric model involves a balanced exchange: the communicator not only sends out information but also actively listens to feedback, and both sides may adjust their views or actions through interaction.

Utility: The practical usefulness and relevance of a visualization, specifically its ability to help viewers achieve their goals or meet informational needs.

APPENDIX G. CURRICULUM VITAE

Name-Surname: Duygu Beykal İz

Education:

B.A. Sabancı University, Visual Arts and Visual Communication Design, 2007

M.S.A The University of Sydney, Sydney College of the Arts, 2009

UK AdvanceHE Fellow - 2020 (Reference number: PR185774)

Work Experience:

Doğuş University 2010-2016 (Full-time Instructor), 2016-2025 (Part-time Instructor)

Özyeğin University 2023-2025 (Part-time Instructor)

FSMVÜ Department of Graphic Design 2016-2018 (Part-time Instructor)

Awards and Scholarships:

Fulbright Commission Scholarship Grantee for 2007-2008

2008 Australian Government Endeavour Award for Turkey scholarship recipient

Scientific Publications:

Beykal Iz, D., Karapars, G. Z., (2024). Measures of Information Visualizations in Design Studio Education: Designing Climate Change Visualizations, *Journal of Design Studio*, V.6, N2, pp 337-356 https://doi.org/10.46474/jds.1578708

Nikkhah, A., Nikkhah, H., Shahbazi, A., Zarin, M. K. Z., Beykal Iz, D., Ebadi, M.-T., Fakhroleslam, M., & Beykal, B. (2024). Cumin and eucalyptus essential oil standardization using fractional distillation: Data-driven optimization and techno-economic analysis. *Food and Bioproducts Processing*, *143*, 90–101. https://doi.org/10.1016/j.fbp.2023.10.005

Beykal, D. (2009). The phenomenological study of an art process. *The International Journal of the Arts in Society* (vol. 4, no:1). Melbourne, Australia; Commonground Publishing. https://doi.org/10.18848/1833-1866/CGP/v04i01/35546