Introducing a procedure to perform the Analytic Hierarchy Process with own survey data obtained from *SoSci Survey* platform using R-package *ahpsurvey*

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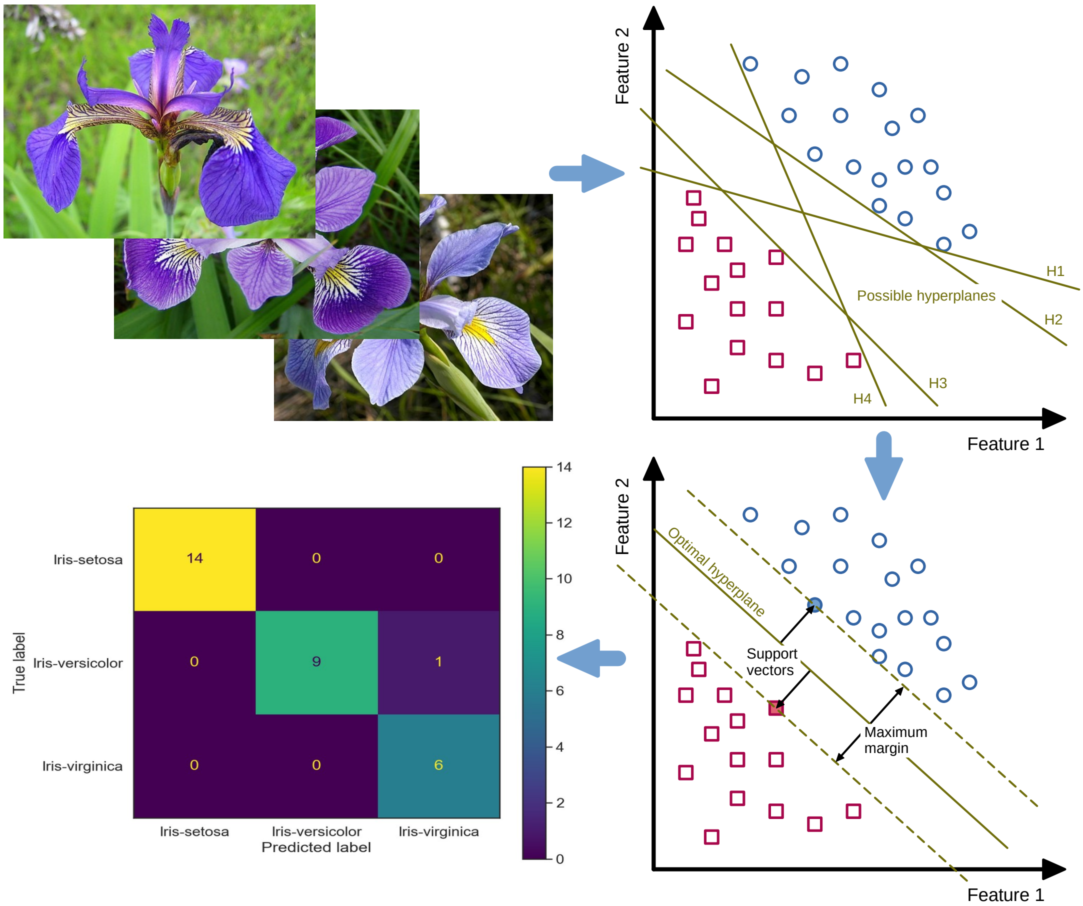

Anyone who wants to seriously deal with the emerging topic of our time "Artificial Intelligence (AI)" cannot avoid dealing with the basic mathematical models and algorithms from the field of "Machine Learning (ML)" as a subset of AI. However, someone who opens the door for the first time to this equally very exciting as well as arbitrarily complex and, at first glance, confusing world will very quickly be overwhelmed. Here, it is a good idea to consult introductory and systematic tutorials. Therefore, this Getting Started tutorial systematically demonstrates the typical ML work process step-by-step using the very powerful and performant "Support Vector Classifier (SVC)" and the widely known and exceptionally beginner-friendly "Iris Dataset". Furthermore, the selection of the "correct" SVC kernel and its parameters are described and their effects on the classification result are shown.

Contents

1 Introduction

The **Analytic Hierarchy Process (AHP)** is a common and now widely used method to decide on an alternative based on several different criteria (see Wikipedia: AHP 2023). Often the weighting of the respective criteria is done by a small number of decision makers or even a single decision maker. The AHP is then relatively easy to implement, both organizationally and technically.

Much less often, the weighting of criteria used for decision-making is done by a variety of different stakeholders. However, especially for decision-making with high social relevance, the involvement of many stakeholders is very important. At this point, the following questions arise:

1. How do I collect the data?
2. Which software or tool can perform an AHP with data from the survey of a large number of stakeholders?
3. How can data collection and processing be combined in a way that is both organizationally and technically sensible and time-effective?

As part of the DFG-funded project "Edible Cities", the objective was to evaluate different forms of urban agriculture using AHP with regard to their sustainability. The prerequisite for this was the involvement of numerous stakeholders from various target groups in the weighting of the previously selected criteria and sub-criteria. The pairwise comparisons of criteria and sub-criteria required for weighting should be performed by means of an online survey, which should ideally be followed directly by the AHP calculation automatically. Since the stakeholders interviewed here were predominantly people from the non-scientific environment, the survey had to be structured to suit these target groups.

To the authors' knowledge, the only online tool available for conducting a survey in combination with a directly subsequent criteria weighting is "AHP-OS" from BPMSG (Business Performance Management Singapore).

Reflecting the above requirements, especially with regard to the target groups, "AHP-OS" appeared unsuitable, however, as it is too strongly designed to generate consistent datasets. For this purpose, participants are asked to reconsider their decisions several times, if necessary, and to adjust them in the direction of consistency. This very scientific approach would not have been appropriate for the intended target groups.

Therefore, the authors followed the approach of separating the stakeholder survey and the subsequent weighting of the criteria in organizational and technical terms.

This paper introduces, for the first time, a procedure in which data collected using the online survey platform SoSci Survey are subsequently processed with the `ahpsurvey` package (see Cho 2019). This package is exclusively available for the statistical programming language **R** and, to the authors' knowledge, is the only tool that meets the requirements outlined in the previous sections.

```
@TODO:
The following remains to be revised and adjusted.
```

Why we use a Jupyter notebook to to publish the R program examples:

Jupyter is a new **open source** alternative to the proprietary numerical software Mathematica from **Wolfram Research** that is well on the way to become a **standard for exchanging research results** (Somers 2018; Romer 2018).

Originally Jupyter was intended as an IDE for the programming languages **Julia** and **Python**. Besides that it is also possible to install other interpreter kernels, such as the **IRkernel** for **R**. This can be interesting if the IDE **RStudio Desktop** is not available on the target platform used. For example, it is very difficult to install RStudio on the ARM-based embedded computer **Raspberry Pi** due to many technical dependencies. In contrast, using the R kernel in JupyterLab on the Raspberry Pi works very well and performant.

2 Loading of used R packages and definition of global functions

2.1 Install missing packages if not present yet

In order to load the R packages used in the next sections, they must be installed in the R environment. The following function checks for the presence of the packages and installs the missing ones.

Attention: For some R packages, several dependencies have to be installed first using the package manager of the operating system, e.g. `apt install <package name>`.

In general, the use of R version ≥ 4.0 is strongly recommended. In particular, the `ahpsurvey` package, which is essential for calculating the AHP, depends on the `randomNames` package. However, this is only available starting with R version ≥ 4.0 (refer to randomNames: Generate Random Given and Surnames).

This can be problematic especially with slightly older systems, e.g. on the operating system **Raspbian buster** for the very well-known **Raspberry Pi**, R is only available in version 3.5.2. Upgrading R in Raspbian following the instructions on https://cran.rstudio.com/bin/linux/debian/#debian-buster-stable has not succeeded for the authors so far.

[1]:
```
# List of R packages that are used in this script
list.of.packages <- c("data.table",
                      "ggplot2",
                      "tidyr",
                      "dplyr",
                      "magrittr",
                      "ahpsurvey",
                      "knitr",
                      "IRdisplay",
                      "forcats")

# Query the already installed packages and save the missing ones in a new list
missing.packages <- list.of.packages[!(list.of.packages
                                       %in% installed.packages()[,"Package"])]

# Install missing packages
if(length(missing.packages)) {
    install.packages(missing.packages)
} else {
    print("All required packages are installed.")
}
```

```
[1] "All required packages are installed."
```

2.2 Load R packages

After proving in the previous section that all required R packages are installed, they can be loaded in the following subsections.

2.2.1 Load package `data.table`

The `data.table` package is used for **reading and editing tables**.

Note: This package inherits from `data.frame`.

[2]:
```
library(data.table)
```

2.2.2 Load package `ggplot2`

The package `ggplot2` is used to **plot beautiful diagrams**.

[3]:
```
library(ggplot2)
```

2.2.3 Load packages knitr and IRdisplay

The `kable()` function from the package `knitr` is used to output dataframes as markdown tables.

The `display_markdown()` function from the package `IRdisplay` is used to **render markdown tables** in the notebook as well as in the compiled PDF output.

[4]:
```
library(knitr)
library(IRdisplay)
```

2.2.4 Load package tidyr

The package `tidyr` is used to **reshape dataframes** and provides functions like `gather()` or `spread()`. Some examples for the application can be found here: Reshaping your data with tidyr.

[5]:
```
library(tidyr)
```

2.2.5 Load package dplyr

The package `dplyr` is necessary to **manipulate dataframes** using functions like `select()`, `mutate()` and `left_join()`.

Hint: Annoying messages on package loading regarding masked functions can be suppressed by setting the parameter `warn.conflicts=FALSE` when calling the `library()` function.

[6]:
```
library(dplyr, warn.conflicts=FALSE)
```

2.2.6 Load package magrittr

The package `magrittr` provides the **pipe functionality** and can be used to create more effective code for processing large datasets. What pipes of the form like `%>%` are and how to use them is described here: R-Programmierung: Was ist %>%?.

HINT: The pipe functionality is already available by loading the library `tidyr` - so you don't have to load it explicitly.

[7]:
```
library(magrittr, warn.conflicts=FALSE)
```

2.2.7 Load package forcats

The `fct_inorder()` function from the package `forcats` is used to **reorder the discrete levels of diagram axes** according to the intended order of attributes.

[8]:
```
library(forcats)
```

2.2.8 Load package ahpsurvey

The package `ahpsurvey` contains all the necessary mathematical and statistical methods to run the **analytical hierarchy process (AHP)**.

[9]:
```
library(ahpsurvey)
```

2.3 Function to format dataframes as markdown tables

Following function **formats given dataframes as markdown tables** using the `kable()` function from the `knitr` package.

The `display_markdown()` function from the package `IRdisplay` is used to **render markdown tables** in the notebook as well as in the compiled PDF output.

[10]:
```
func_render_md_tables <- function(df_table, str_table_header) {
    # Format the dataframe as a markdown table using
    # the 'kable()' function from the 'knitr' package.
    table_out <- kable(
        df_table,
        format = "markdown",
        # digits = 2,
        caption = str_table_header)

    # print(table_out)
    display_markdown(as.character(table_out))
}
```

3 Prepare raw CSV input data from SoSci Survey for analytical hierarchy process (AHP)

The survey was conducted on the SoSci Survey platform and the results were exported as CSV files.

In this main section the CSV files are prepared in such a way that in the following main section the AHP can be carried out using the R package `ahpsurvey`.

3.1 Set globally used input and output folders for preparing raw CSV data

The following global variables are used to store the input and output folders for CSV file preparation.

[11]:
```
str_input_path_prep = "./input_data_from_survey"
str_output_path_prep = "./output_data_manipulated"
```

3.2 Define functions to prepare the survey data for further analysis

The following functions are used to read the survey data from the input CSV files, to prepare the data structure for further analysis with the R package `ahpsurvey` and to store the results in the output CSV files.

3.2.1 Function to read the survey data from CSV files to dataframe objects

This function reads a CSV file and stores the data in four different dataframes by selecting different columns for each. The four dataframes contain the **main criteria**, the **environmental**, the **social**, or the **economic sub-criteria**.

[12]:
```
func_readCSVdata_to_dataframes <- function(str_CSVfilename) {

  # Criteria (main criteria)
  df_mySurvey_1 <- fread(
    file = str_CSVfilename, encoding = "UTF-8",
    header = TRUE, sep = "\t", quote = "\"",
    # dec = ".", row.var = "CASE",
    select = c("CASE", "AK01", "AK02", "AK03",
               "RK01_01", "RK02_01", "RK03_01",
```

```
              "RK04_01", "RK05_01", "RK06_01")
  )

  # Environmental sub-criteria
  df_mySurvey_2 <- fread(
    file = str_CSVfilename, encoding = "UTF-8",
    header = TRUE, sep = "\t", quote = "\"",
    # dec = ".", row.names = "CASE",
    select = c("CASE", "AU01", "AU02", "AU03",
               "RU01_01", "RU02_01", "RU03_01",
               "RU04_01", "RU05_01", "RU06_01")
  )

  # Social sub-criteria
  df_mySurvey_3 <- fread(
    file = str_CSVfilename, encoding = "UTF-8",
    header = TRUE, sep = "\t", quote = "\"",
    # dec = ".", row.names = "CASE",
    select = c("CASE", "AS01", "AS02", "AS03",
               "RS01_01", "RS02_01", "RS03_01",
               "RS04_01", "RS05_01", "RS06_01")
  )

  # Economic sub-criteria
  df_mySurvey_4 <- fread(
    file = str_CSVfilename, encoding = "UTF-8",
    header = TRUE, sep = "\t", quote = "\"",
    # dec = ".", row.names = "CASE",
    select = c("CASE", "AW01", "AW02", "AW03",
               "RW01_01", "RW02_01", "RW03_01",
               "RW04_01", "RW05_01", "RW06_01")
  )

  output <- list(df_mySurvey_1, df_mySurvey_2, df_mySurvey_3, df_mySurvey_4)

  return(output)
}
```

3.2.2 Function to adapt the exported survey data to Saaty scale

For the **comparison of two attributes**, Saaty introduced a scale of nine rating items shown in the following table (see Saaty 1987):

Table 1: Nine rating items according to Saaty (adapted from source: Cho 2019)

Rating	Definition
1	Two attributes are equally important
2	Between 1 and 3
3	The preferred attribute is slightly more important
4	Between 3 and 5
5	The preferred attribute is moderately more important
6	Between 5 and 7
7	The preferred attribute is strongly more important
8	Between 7 and 9
9	The preferred attribute is absolutely more important

To be able to describe the comparison of two attributes uniquely, negative values as well as positive values are introduced for the rating items. **Negative** values prefer the *Attribute X* and **positive** values the *Attribute Y*. A value of 1 means that both attributes are **equally weighted**, i.e. equally important. Note that the values 0 and -1 **do not** exist. Thus, Saaty's 17-step scale will result as follows:

Attribute X -9 -8 -7 ... -3 -2 **1** 2 3 ... 7 8 9 *Attribute Y*

The package `ahpsurvey` employs the 17-step scale according to Saaty (see Cho 2019).

On the one hand, Saaty's 17-step scale was not technically well implementable on the survey platform used SoSci Survey. On the other hand, it had been too fine-granular for the mostly non-scientific target groups of participants.

Therefore, a **2-stage query** was chosen as an alternative approach. In **stage 1**, it was first asked whether, and if so, which of the two attributes was preferred and thus given a higher weighting. Stage 1 resulted in the following encoding:

- -1: *Attribute X* and *Attribute Y* **equally important**
- 1: *Attribute X* **more important** than *Attribute Y*
- 2: *Attribute X* **less important** than *Attribute Y*

With different weightings, the respondents in **stage 2** had to decide how much more important the respective attribute was to them on a scale of 1 to 8. Thereby, 1 corresponds to 2, 2 to 3, etc. of the rating items according to Saaty. See the following figure:

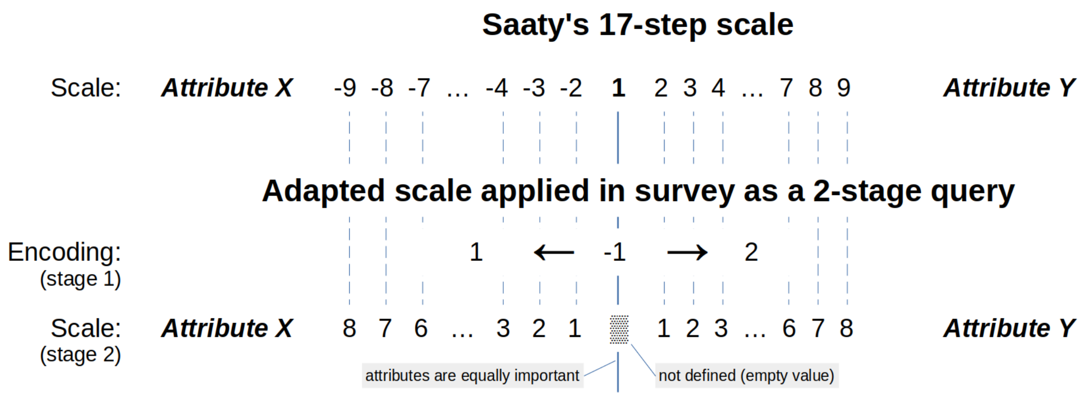

Figure 1: Transformation from the Saaty's 17-step scale to the encoded scale applied by a 2-stage query (source: Kasper, license: CC BY-SA 4.0)

The survey results were exported from *SoSci Survey* in the form of an **encoded scale** as a CSV file. With the following function `func_adaptData2SaatyScale` this now has to be converted back to the Saaty scale in order to run AHP with the R package `ahpsurvey`.

The values of the encoding and those of the weighting have to be taken from the CSV file from three different columns per pairwise attribute comparison. For example, when comparing the two attributes "Microclimate and Hydrology (Clim)" and "Biodiversity (BDiv)", the column `AU01` contains the encoding and the columns `RU01_01` or `RU02_01` the respective weighting.

The following example shows the three possible cases and the conversion to the Saaty scale.

Case 1:

- if `AU01` = -1, then set weighting = 1
- attributes `Clim` and `BDiv` are equally important
- values in columns `RU01_01` or `RU02_01` are ignored

Case 2:

- if `AU01` = 1, then set weighting = -1 ∗ `RU01_01` − 1
- the attribute `Clim` is more important than `BDiv`

Case 3:

- if `AU01` = 2, then set weighting = `RU02_01` + 1
- the attribute `Clim` is less important than `BDiv`

The function `func_adaptData2SaatyScale` returns a new dataframe with the weightings converted to the Saaty scale from three pairwise comparisons of the criteria or sub-criterion.

[13]:
```
func_adaptData2SaatyScale <- function(df_inputData,
                                      vec_colnames_search_1,
                                      vec_colnames_search_2,
                                      vec_colnames_out) {
  # Generate new dataframe ...
  df_outputData <- data.frame(matrix(ncol = 3, nrow = 0))
  # ... and name the columns
  colnames(df_outputData) <- vec_colnames_out

  # Generate 1. column
  for ( row_idx in 1:nrow(df_inputData) ) {
    # Filter column names by vector element
    if (df_inputData[row_idx, colnames(df_inputData)
        %in% vec_colnames_search_1[1], with=FALSE] == 1) {
      int_tmp_val <- as.integer(df_inputData[row_idx, colnames(df_inputData)
                     %in% vec_colnames_search_2[1], with=FALSE])
      int_tmp_val <- int_tmp_val * -1 - 1

      df_outputData[row_idx, vec_colnames_out[1]] <- int_tmp_val
    }
    else if (df_inputData[row_idx, colnames(df_inputData)
             %in% vec_colnames_search_1[1], with=FALSE] == -1) {
      df_outputData[row_idx, vec_colnames_out[1]] <- 1
    }
    else if (df_inputData[row_idx, colnames(df_inputData)
             %in% vec_colnames_search_1[1], with=FALSE] == 2) {
      int_tmp_val <- as.integer(df_inputData[row_idx, colnames(df_inputData)
                     %in% vec_colnames_search_2[2], with=FALSE])
      int_tmp_val <- int_tmp_val + 1

      df_outputData[row_idx, vec_colnames_out[1]] <- int_tmp_val
    }
  }

  # Generate 2. column
  for ( row_idx in 1:nrow(df_inputData) ) {
    # Filter column names by vector element
    if (df_inputData[row_idx, colnames(df_inputData)
        %in% vec_colnames_search_1[2], with=FALSE] == 1) {
      int_tmp_val <- as.integer(df_inputData[row_idx, colnames(df_inputData)
                     %in% vec_colnames_search_2[3], with=FALSE])
      int_tmp_val <- int_tmp_val * -1 - 1

      df_outputData[row_idx, vec_colnames_out[2]] <- int_tmp_val
    }
    else if (df_inputData[row_idx, colnames(df_inputData)
             %in% vec_colnames_search_1[2], with=FALSE] == -1) {
      df_outputData[row_idx, vec_colnames_out[2]] <- 1
    }
    else if (df_inputData[row_idx, colnames(df_inputData)
             %in% vec_colnames_search_1[2], with=FALSE] == 2) {
```

```
      int_tmp_val <- as.integer(df_inputData[row_idx, colnames(df_inputData)
                     %in% vec_colnames_search_2[4], with=FALSE])
      int_tmp_val <- int_tmp_val + 1

      df_outputData[row_idx, vec_colnames_out[2]] <- int_tmp_val
    }
  }

  # Generate 3. column
  for ( row_idx in 1:nrow(df_inputData) ) {
    # Filter column names by vector element
    if (df_inputData[row_idx, colnames(df_inputData)
        %in% vec_colnames_search_1[3], with=FALSE] == 1) {
      int_tmp_val <- as.integer(df_inputData[row_idx, colnames(df_inputData)
                     %in% vec_colnames_search_2[5], with=FALSE])
      int_tmp_val <- int_tmp_val * -1 - 1

      df_outputData[row_idx, vec_colnames_out[3]] <- int_tmp_val
    }
    else if (df_inputData[row_idx, colnames(df_inputData)
             %in% vec_colnames_search_1[3], with=FALSE] == -1) {
      df_outputData[row_idx, vec_colnames_out[3]] <- 1
    }
    else if (df_inputData[row_idx, colnames(df_inputData)
             %in% vec_colnames_search_1[3], with=FALSE] == 2) {
      int_tmp_val <- as.integer(df_inputData[row_idx, colnames(df_inputData)
                     %in% vec_colnames_search_2[6], with=FALSE])
      int_tmp_val <- int_tmp_val + 1

      df_outputData[row_idx, vec_colnames_out[3]] <- int_tmp_val
    }
  }

  # Return rescaled dataframe
  return(df_outputData)
}
```

3.2.3 Function to write resulting dataframes to CSV files

With this function, the results of the data preparation are saved in output CSV files.

[14]:
```
func_writeDataframe_to_CSVfile <- function(str_path, str_CSVfilename,
                                           df_dataframe, str_filenameExtension) {
  # How to split the file name on second underscore,
  # was found here: https://stackoverflow.com/a/32398489
  list_str_split <- strsplit(sub('(^[^_]+_[^_]+)_(.*)$', '\\1 \\2',
                                 str_CSVfilename), ' ')

  # Extend the file name prefix and glue together with old suffix
  str_CSVfilename_extended <- paste(list_str_split[[1]][1],
                                    str_filenameExtension,
                                    list_str_split[[1]][2], sep="_")

  # Extend file name by path
  str_CSVfilename_extended <- paste(str_path, str_CSVfilename_extended, sep="/")

  write.table(df_dataframe, file = str_CSVfilename_extended,
```

```
               fileEncoding = "UTF-8", row.names = FALSE,
               col.names = TRUE, sep = "\t", quote = TRUE)
}
```

3.3 Create dataframe handling the file names of input CSV data (raw data from survey)

[15]:
```
df_csvInputFiles <- data.table(
  file_idx = 1:4,
  keys = c("all", "CA", "NGO", "PE"),
  filenames = c("rdata_all_AHP_edible_Cities_2022-03-18_09-53.csv",
                "rdata_CA_AHP_edible_Cities_2022-03-18_10-28.csv",
                "rdata_NGO_AHP_edible_Cities_2022-03-18_10-40.csv",
                "rdata_PE_AHP_edible_Cities_2022-03-18_10-41.csv"),
  descriptions = c("all target groups together",
                   "City Administrations",
                   "Non-Governmental Organisations",
                   "Practitioners and Experts")
)

func_render_md_tables(df_csvInputFiles, "File table for handling the file names
                      of input CSV data (raw data from survey)")
```

Table 2: File table for handling the file names of input CSV data (raw data from survey)

file_idx	keys	filenames	descriptions
1	all	rdata_all_AHP_edible_Cities_2022-03-18_09-53.csv	all target groups together
2	CA	rdata_CA_AHP_edible_Cities_2022-03-18_10-28.csv	City Administrations
3	NGO	rdata_NGO_AHP_edible_Cities_2022-03-18_10-40.csv	Non-Governmental Organisations
4	PE	rdata_PE_AHP_edible_Cities_2022-03-18_10-41.csv	Practitioners and Experts

3.4 Prepare the data and store it in new CSV files for each criterion

3.4.1 Criteria (main criteria)

Walk over all input CSV files, select necessary columns, filter cells by given algorithm, and write the results to output CSV files:

[16]:
```
vec_colnames_search_1 <- c('AK01', 'AK02', 'AK03')
vec_colnames_search_2 <- c('RK01_01', 'RK02_01', 'RK03_01',
                           'RK04_01', 'RK05_01', 'RK06_01')
vec_colnames_out <- c('Envi_Soci', 'Envi_Econ', 'Soci_Econ')

for ( row_idx in 1:nrow(df_csvInputFiles) ) {
  # Create a list of dataframes from current input CSV file
  str_filename <- paste(str_input_path_prep,
                        df_csvInputFiles[row_idx, filenames], sep="/")
  list_dataframes <- func_readCSVdata_to_dataframes(str_filename)

  # Adapt the encoded scale of the survey to the 17-step Saaty's scale
  # in the input dataframes
```

```
  df_surveyData_rescaled <- func_adaptData2SaatyScale(list_dataframes[[1]],
                                                      vec_colnames_search_1,
                                                      vec_colnames_search_2,
                                                      vec_colnames_out)

  # Write rescaled dataframes to output CSV file
  func_writeDataframe_to_CSVfile(str_output_path_prep,
                                 df_csvInputFiles[row_idx, filenames],
                                 df_surveyData_rescaled, "crit")
}
```

3.4.2 Environmental sub-criteria

Walk over all input CSV files, select necessary columns, filter cells by given algorithm, and write the results to output CSV files:

[17]:
```
vec_colnames_search_1 <- c('AU01', 'AU02', 'AU03')
vec_colnames_search_2 <- c('RU01_01', 'RU02_01',
                           'RU03_01', 'RU04_01',
                           'RU05_01', 'RU06_01')
vec_colnames_out <- c('Clim_BDiv', 'Clim_CiEc', 'BDiv_CiEc')

for ( row_idx in 1:nrow(df_csvInputFiles) ) {
  # Create a list of dataframes from current input CSV file
  str_filename <- paste(str_input_path_prep,
                        df_csvInputFiles[row_idx, filenames], sep="/")
  list_dataframes <- func_readCSVdata_to_dataframes(str_filename)

  # Adapt the encoded scale of the survey to the 17-step Saaty's scale
  # in the input dataframes
  df_surveyData_rescaled <- func_adaptData2SaatyScale(list_dataframes[[2]],
                                                      vec_colnames_search_1,
                                                      vec_colnames_search_2,
                                                      vec_colnames_out)

  # Write rescaled dataframes to output CSV file
  func_writeDataframe_to_CSVfile(str_output_path_prep,
                                 df_csvInputFiles[row_idx, filenames],
                                 df_surveyData_rescaled, "env")
}
```

3.4.3 Social sub-criteria

Walk over all input CSV files, select necessary columns, filter cells by given algorithm, and write the results to output CSV files:

[18]:
```
vec_colnames_search_1 <- c('AS01', 'AS02', 'AS03')
vec_colnames_search_2 <- c('RS01_01', 'RS02_01', 'RS03_01',
                           'RS04_01', 'RS05_01', 'RS06_01')
vec_colnames_out <- c('KEdu_Comm', 'KEdu_Part', 'Comm_Part')

for ( row_idx in 1:nrow(df_csvInputFiles) ) {
  # Create a list of dataframes from current input CSV file
  str_filename <- paste(str_input_path_prep,
                        df_csvInputFiles[row_idx, filenames], sep="/")
  list_dataframes <- func_readCSVdata_to_dataframes(str_filename)
```

```
  # Adapt the encoded scale of the survey to the 17-step Saaty's scale
  # in the input dataframes
  df_surveyData_rescaled <- func_adaptData2SaatyScale(list_dataframes[[3]],
                                                     vec_colnames_search_1,
                                                     vec_colnames_search_2,
                                                     vec_colnames_out)

  # Write rescaled dataframes to output CSV file
  func_writeDataframe_to_CSVfile(str_output_path_prep,
                                df_csvInputFiles[row_idx, filenames],
                                df_surveyData_rescaled, "soc")
}
```

3.4.4 Economic sub-criteria

Walk over all input CSV files, select necessary columns, filter cells by given algorithm, and write the results to output CSV files:

[19]:
```
vec_colnames_search_1 <- c('AW01', 'AW02', 'AW03')
vec_colnames_search_2 <- c('RW01_01', 'RW02_01', 'RW03_01',
                           'RW04_01', 'RW05_01', 'RW06_01')
vec_colnames_out <- c('Qual_LVCs', 'Qual_Affo', 'LVCs_Affo')

for ( row_idx in 1:nrow(df_csvInputFiles) ) {
  # Create a list of dataframes from current input CSV file
  str_filename <- paste(str_input_path_prep,
                        df_csvInputFiles[row_idx, filenames], sep="/")
  list_dataframes <- func_readCSVdata_to_dataframes(str_filename)

  # Adapt the encoded scale of the survey to the 17-step Saaty's scale
  # in the input dataframes
  df_surveyData_rescaled <- func_adaptData2SaatyScale(list_dataframes[[4]],
                                                     vec_colnames_search_1,
                                                     vec_colnames_search_2,
                                                     vec_colnames_out)

  # Write rescaled dataframes to output CSV file
  func_writeDataframe_to_CSVfile(str_output_path_prep,
                                df_csvInputFiles[row_idx, filenames],
                                df_surveyData_rescaled, "eco")
}
```

4 Application of the processed survey data in the analytical hierarchy process (AHP)

4.1 Set globally used input and output folders for processing AHP

[20]:
```
str_input_path_ahp = "./output_data_manipulated"
str_output_path_ahp = "./output_data_AHP"
```

4.2 Define functions for processing AHP

4.2.1 Function to read in the processed survey data from CSV files to dataframes

Define a function for reading in a CSV file to a date frame.

[21]:
```
func_readCSVdata_to_dataframe <- function(str_CSVfilename) {

  df_CSVdata <- fread(
    file = str_CSVfilename, encoding = "UTF-8",
    header = TRUE, sep = "\t", quote = "\""
    )

  return(df_CSVdata)
}
```

4.2.2 Function to generate a dataframe with *eigentrue values* (weights)

[22]:
```
func_genEigentrue_to_dataframe <- function(df_surveyData, vec_attributes) {
  list_mat_judgement <- df_surveyData %>%
    ahp.mat(vec_attributes, negconvert = TRUE)

  df_eigentrue <- ahp.indpref(list_mat_judgement,
                              vec_attributes, method = "eigen")

  return(df_eigentrue)
}
```

4.2.3 Function to generate an array with consistency ratios

[23]:
```
func_genCR_to_arr <- function(df_surveyData, vec_attributes) {
  arr_cr <- df_surveyData %>%
    ahp.mat(vec_attributes, negconvert = TRUE) %>%
    ahp.cr(vec_attributes, ri=0.58)

  return(arr_cr)
}
```

4.2.4 Function to generate a dataframe with consistency ratios

[24]:
```
func_genCR_to_dataframe <- function(df_surveyData, vec_attributes,
                                    arr_cr, consistency_thres=0.1, str_CRlabel) {
  df_cr <- df_surveyData %>%
    ahp.mat(vec_attributes, negconvert = TRUE) %>%
    ahp.cr(vec_attributes, ri=0.58) %>%
    data.frame() %>%
    mutate(rowid = 1:length(arr_cr),
           arr_cr.dum = as.factor(ifelse(arr_cr <= consistency_thres, 1, 0)))

  # Rename column with consistency ratios
  colnames(df_cr)[1] <- str_CRlabel

  return(df_cr)
}
```

4.2.5 Function to visualize individual priorities and consistency ratios

[25]:
```
func_visuPriosCRs <- function(df_surveyData, df_cr, arr_cr,
                              consistency_thres = 0.1, vec_attributes,
                              df_eigentrue, vec_labels,
                              str_image_filename, str_title) {
  # Select columns 'arr_cr.dum' and 'rowid' from input dataframe 'df_cr'
  # 'arr_cr.dum': Binary representation of the consistency ratio
  #               (0: inconsistent; 1: consistent)
  df_cr_sel <- df_cr %>%
    select(arr_cr.dum, rowid)

  # Generate AHP pairwise matrices from survey data
  mat_ahp <- ahp.mat(df_surveyData, atts = vec_attributes, negconvert = TRUE)

  # Compute priority weights of individual decision-makers
  df_prio_weights <- ahp.indpref(mat_ahp, vec_attributes, method = "eigen")

  # Add column 'rowid' from dataframe 'df_eigentrue'
  df_prio_weights <- mutate(df_prio_weights, rowid = 1:nrow(df_eigentrue))

  # Left join dataframes 'df_prio_weights' and 'df_cr_sel' by column 'rowid'
  df_prio_weights_binCR <- left_join(df_prio_weights, df_cr_sel, by = "rowid")

  # Gather columns of 'df_prio_weights_binCR' into key-value pairs
  # The function 'all_of(vec_attributes)' selects data-variables listed
  # in the character vector 'vec_attributes'
  li_binCR_attr_weights <- gather(df_prio_weights_binCR,
                                  all_of(vec_attributes),
                                  key = "var", value = "pref")

  # Create the violin plots with overlaid box plots.
  # Important: The function "fct_inorder()" is necessary to reorder
  # the discrete levels of the diagram axes according to
  # the intended order of the attributes.
  # Otherwise, the order will be automatically set alphanumerically
  # and will not match the attribute labels later.
  # refer: https://stackoverflow.com/a/41417136
  plt <- ggplot(li_binCR_attr_weights, aes(x = fct_inorder(var), y = pref)) +
    # Add a violin plot
    geom_violin(alpha = 0.6, width = 0.8, color = "transparent", fill = "gray") +
    # 'geom_jitter()' is a shortcut for 'geom_point(position = "jitter")'
    # Adds a small amount of random variation to the location of each point
    # to handle overplotting caused by discreteness in smaller datasets
    geom_jitter(alpha = 0.6, height = 0, width = 0.1, aes(color = arr_cr.dum)) +
    # Add a box plot
    geom_boxplot(alpha = 0, width = 0.3, color = "#808080") +
    # Set discrete levels of the diagram X-axis according to
    # the corresponding attribute labels
    scale_x_discrete("Attribute", label = vec_labels) +

    # Configure the diagram Y-axis to display continuos data with
    # scale in percent and choose where the ticks appear by setting 'breaks'
    scale_y_continuous("Weight (dominant eigenvalue)",
                       labels = scales::percent,
                       breaks = c(seq(0,0.7,0.1))) +

    # Hide the title of the legend
```

```
    guides(color=guide_legend(title=NULL)) +

    # Set the discrete color scale according to the binarized consistency ratio
    # and use the Unicode character '\u2264' for '<='
    scale_color_discrete(breaks = c(0,1),
                         labels = c(paste("CR >", consistency_thres),
                                    paste("CR \u2264", consistency_thres))) +

    # Set caption text to be displayed in the bottom-right of the plot
    # with number of rows and mean value of the consistency ratio
    labs(NULL, caption = paste("n =", nrow(df_surveyData), ",", "Mean CR =",
                               round(mean(arr_cr), 3))) +

    # Set theme of the plot to 'theme_light()'
    theme_light() +

    # Set the title of the diagram
    ggtitle(str_title)

  print(plt)

  # Save generated ggplot graphics to PNG image files
  ggsave(filename = str_image_filename, width = 7, height = 7, dpi = 300)
}
```

4.2.6 Function to generate geometric mean values from individual judgement matrices

[26]:
```
func_aggpref_gmean <- function(df_surveyData, vec_attributes,
                               arr_cr, consistency_thres=0.1, str_CRlabel) {
  df_cr <- df_surveyData %>%
    ahp.mat(vec_attributes, negconvert = TRUE) %>%
    ahp.cr(vec_attributes, ri=0.58) %>%
    data.frame() %>%
    mutate(rowid = 1:length(arr_cr),
           arr_cr.dum = as.factor(ifelse(arr_cr <= consistency_thres, 1, 0)))

  # Rename column with consistency ratios
  colnames(df_cr)[1] <- str_CRlabel

  # Combine dataframe 'df_cr' with raw survey data ('df_surveyData')
  df_cr_wRaw <- cbind(df_cr, df_surveyData)

  # Remove rows, where 'arr_cr.dum' == 0 (inconsistent data)
  df_cr_wRaw_cons <- df_cr_wRaw[df_cr_wRaw$arr_cr.dum != 0, ]

  # Get individual judgement matrices from last 3 columns
  list_mat_judgement <- df_cr_wRaw_cons[tail(names(df_cr_wRaw_cons), 3)] %>%
    ahp.mat(vec_attributes, negconvert = TRUE)

  # Get geometric mean values from judgement matrices
  list_gmean_l <- ahp.aggpref(list_mat_judgement, vec_attributes,
                              method = "eigen", aggmethod = "geometric")

  return(list_gmean_l)
}
```

4.2.7 Function to normalize the geometric mean values

[27]:
```
func_norm_gmean <- function(list_gmeans) {
  # Normalize the geometric means so that the sum of the values is 1,
  # what corresponds to 100%
  df_gmean_l <- data.frame(list_gmeans)
  # Rename column with geometric mean values (raw)
  colnames(df_gmean_l)[1] <- "gmean.raw"

  gmean_sum <- 0
  for ( val in list_gmeans ) {
    gmean_sum <- gmean_sum + val
  }
  df_gmean_l["Sum", 1] <- gmean_sum

  for (idx in 1:length(list_gmeans)) {
    gmean_norm <- list_gmeans[[idx]] / gmean_sum
    df_gmean_l[idx, "gmean.norm"] <- gmean_norm
  }

  gmean_sum_norm <- 0
  # Iterate over all rows except the last, because this is the sum itself
  for ( row in 1:(nrow(df_gmean_l)-1) ) {
    gmean_sum_norm <- gmean_sum_norm + df_gmean_l[row, 2]
  }
  df_gmean_l["Sum", 2] <- gmean_sum_norm

  return(df_gmean_l)
}
```

4.2.8 Function to process the ahpsurvey and create violin plots with overlaid box plots

[28]:
```
func_process_ahpsurvey <- function(df_csvInputFiles, str_participants_group,
                                   str_input_path_ahp, str_output_path_ahp,
                                   df_attributes_labels) {
    row_start <- 1
    row_end <- 3

    df_outputTable <- data.table()

    for (file_idx in 1:nrow(df_csvInputFiles)) {
        # Create dataframe from current input CSV file
        str_filename <- paste(str_input_path_ahp,
                              df_csvInputFiles[file_idx, filenames], sep = "/")
        df_processed_survey_data <- func_readCSVdata_to_dataframe(str_filename)

        # Create vectors for attributes and labels from a subset
        # of dataframe 'df_attributes_labels_XXX'
        vec_atts <- df_attributes_labels[c(row_start:row_end), attr]
        vec_labels <- df_attributes_labels[c(row_start:row_end), labels]

        # Shift row interval for next iteration
        row_start <- row_start + 3
        row_end <- row_end + 3

        # Create title string for violin plots
        # Hint: 1st paste() function is only used to break the code to a new line
```

```
        str_violin_title <- paste("Display priorities and ",
                                  "consistency ratios for attributes:", sep = "")
        str_violin_title <- paste(str_violin_title, vec_atts[1], sep = " ")
        # Extend title string by looping through attributes,
        # starting with 2nd element
        for (idx in 2:length(vec_atts)) {
            str_violin_title <- paste(str_violin_title,
                                      vec_atts[idx], sep = ", ")
        }

        # Generate dataframe with eigentrue values (weights)
        df_eigentrue_weights <- func_genEigentrue_to_dataframe(
                                    df_processed_survey_data, vec_atts)

        # Generate an array with consistency ratios
        arr_CRs <- func_genCR_to_arr(df_processed_survey_data, vec_atts)

        # Generate an extended dataframe with consistency ratios
        consistency_thres <- 0.1
        str_CRlabel <- paste("CR", df_csvInputFiles[file_idx, keys], sep = "_")
        df_CRs <- func_genCR_to_dataframe(df_processed_survey_data,
                                          vec_atts, arr_CRs, consistency_thres,
                                          str_CRlabel)

        str_image_filename <- paste("ahp_violin", str_participants_group,
                                    df_csvInputFiles[file_idx, keys], sep = "_")
        # str_image_filename <- paste(str_image_filename, "cleaned", sep = "_")
        str_image_filename <- paste(str_image_filename, ".png", sep = "")
        str_image_filename <- paste(str_output_path_ahp, str_image_filename,
                                    sep = "/")
        func_visuPriosCRs(df_processed_survey_data, df_CRs, arr_CRs,
                          consistency_thres, vec_atts, df_eigentrue_weights,
                          vec_labels, str_image_filename, str_violin_title)

        # Combine dataframes of eigentrue values (weights) with consistency ratios
        df_outputTable <- cbind(df_outputTable, df_eigentrue_weights)
        # Add only specific columns of 'df_CRs' (omit column 'row_id')
        df_outputTable <- cbind(df_outputTable, df_CRs[c(1, 3)])
    }

    # Extend file name by path
    str_CSVfilename_output <- paste("rdata", str_participants_group,
                                    "eigentrue_CRs", sep = "_")
    str_CSVfilename_output <- paste(str_CSVfilename_output,
                                    ".csv", sep = "")
    str_CSVfilename_output <- paste(str_output_path_ahp,
                                    str_CSVfilename_output, sep = "/")

    # Write dataframe 'df_outputTable' to CSV file for
    # further statistical analysis
    write.table(df_outputTable,
        file = str_CSVfilename_output,
        fileEncoding = "UTF-8", row.names = FALSE,
        col.names = TRUE, sep = "\t", quote = TRUE
    )
}
```

4.2.9 Function to calculate aggregated preference weights for consistent datasets

[29]:
```
func_calc_pref_weights <- function(df_csvInputFiles,
                                   str_input_path_ahp,
                                   df_attributes_labels) {
    row_start = 1
    row_end = 3

    for ( file_idx in 1:nrow(df_csvInputFiles) ) {
        # Create dataframe from current input CSV file
        str_filename <- paste(str_input_path_ahp,
                              df_csvInputFiles[file_idx, filenames], sep="/")
        str_file_description <- df_csvInputFiles[file_idx, descriptions]

        df_processed_survey_data <- func_readCSVdata_to_dataframe(str_filename)

        # Create vectors for attributes and labels from a subset
        # of dataframe 'df_attributes_labels_XXX'
        vec_atts <- df_attributes_labels[c(row_start:row_end), attr]
        vec_labels <- df_attributes_labels[c(row_start:row_end), labels]

        # Shift row interval for next iteration
        row_start = row_start + 3
        row_end = row_end + 3

        # Generate an array with consistency ratios
        arr_CRs <- func_genCR_to_arr(df_processed_survey_data, vec_atts)

        str_CRlabel <- paste("CR", df_csvInputFiles[file_idx, keys], sep="_")

        list_gmean <- func_aggpref_gmean(df_processed_survey_data, vec_atts,
                                         arr_CRs, consistency_thres=0.1,
                                         str_CRlabel)

        df_gmean <- func_norm_gmean(list_gmean)

        # Store dataframe of main criteria to calculate the total weights
        # of sub-criteria
        if ( str_file_description == "criteria (main criteria)" ) {
            df_gmean_main_criteria <- df_gmean
        } else if ( str_file_description == "environmental sub-criteria" ) {
            # Multiply column 'gmean.norm' of sub-criteria dataframe
            # by 'Envi' value from main criteria dataframe
            # and store the results in the new column 'gmean.total'
            df_gmean$gmean.total <- df_gmean$gmean.norm *
                                    df_gmean_main_criteria["Envi", "gmean.norm"]

            # Sum up the values of the new column 'gmean.total' and write
            # to row 'Sum' of the same column
            df_gmean["Sum", "gmean.total"] <- sum(df_gmean[c(1:3), "gmean.total"])
        } else if ( str_file_description == "social sub-criteria" ) {
            df_gmean$gmean.total <- df_gmean$gmean.norm *
                                    df_gmean_main_criteria["Soci", "gmean.norm"]

            df_gmean["Sum", "gmean.total"] <- sum(df_gmean[c(1:3), "gmean.total"])
        } else if ( str_file_description == "economic sub-criteria" ) {
            df_gmean$gmean.total <- df_gmean$gmean.norm *
                                    df_gmean_main_criteria["Econ", "gmean.norm"]
```

```
            df_gmean["Sum", "gmean.total"] <- sum(df_gmean[c(1:3), "gmean.total"])
        }

        func_render_md_tables(df_gmean, paste("Aggregated weights for ",
                                              str_file_description))
    }
}
```

4.3 Table with attributes (criteria and sub-criteria) and their labels

[30]:
```
df_attributes_labels <- data.table(
  attr = c("Envi", "Soci", "Econ",
           "Clim", "BDiv", "CiEc",
           "KEdu", "Comm", "Part",
           "Qual", "LVCs", "Affo"),
  labels = c("Environment", "Society", "Economy",
             "Microclimate and Hydrology", "Biodiversity", "Circular economy",
             "Knowledge and Education", "Community Building", "Participation",
             "Food Quality and Safety", "Local Value Chains", "Food Affordability"),
  descriptions = c("main criterion", "main criterion", "main criterion",
                   "environmental sub-criterion", "environmental sub-criterion",␣
 ↪"environmental sub-criterion",
                   "social sub-criterion", "social sub-criterion", "social␣
 ↪sub-criterion",
                   "economic sub-criterion", "economic sub-criterion", "economic␣
 ↪sub-criterion")
)

func_render_md_tables(df_attributes_labels, "Table with attributes and labels")
```

Table 3: Table with attributes and labels

attr	labels	descriptions
Envi	Environment	main criterion
Soci	Society	main criterion
Econ	Economy	main criterion
Clim	Microclimate and Hydrology	environmental sub-criterion
BDiv	Biodiversity	environmental sub-criterion
CiEc	Circular economy	environmental sub-criterion
KEdu	Knowledge and Education	social sub-criterion
Comm	Community Building	social sub-criterion
Part	Participation	social sub-criterion
Qual	Food Quality and Safety	economic sub-criterion
LVCs	Local Value Chains	economic sub-criterion
Affo	Food Affordability	economic sub-criterion

4.4 Create dataframes (tables) handling the file names of processed survey data

4.4.1 File table for all participants

[31]:
```
df_csvInputFiles_all <- data.table(
  file_idx = 1:4,
  keys = c("crit", "env", "soc", "eco"),
  filenames = c("rdata_all_crit_AHP_edible_Cities_2022-03-18_09-53.csv",
```

```
                 "rdata_all_env_AHP_edible_Cities_2022-03-18_09-53.csv",
                 "rdata_all_soc_AHP_edible_Cities_2022-03-18_09-53.csv",
                 "rdata_all_eco_AHP_edible_Cities_2022-03-18_09-53.csv"),
  descriptions = c("criteria (main criteria)",
                   "environmental sub-criteria",
                   "social sub-criteria",
                   "economic sub-criteria")
)

func_render_md_tables(df_csvInputFiles_all,
                      "File table for all participants")
```

Table 4: File table for all participants

file_idx	keys	filenames	descriptions
1	crit	rdata_all_crit_AHP_edible_Cities_2022-03-18_09-53.csv	criteria (main criteria)
2	env	rdata_all_env_AHP_edible_Cities_2022-03-18_09-53.csv	environmental sub-criteria
3	soc	rdata_all_soc_AHP_edible_Cities_2022-03-18_09-53.csv	social sub-criteria
4	eco	rdata_all_eco_AHP_edible_Cities_2022-03-18_09-53.csv	economic sub-criteria

4.4.2 File table for city administrations

[32]:
```
df_csvInputFiles_CA <- data.table(
  file_idx = 1:4,
  keys = c("crit", "env", "soc", "eco"),
  filenames = c("rdata_CA_crit_AHP_edible_Cities_2022-03-18_10-28.csv",
                "rdata_CA_env_AHP_edible_Cities_2022-03-18_10-28.csv",
                "rdata_CA_soc_AHP_edible_Cities_2022-03-18_10-28.csv",
                "rdata_CA_eco_AHP_edible_Cities_2022-03-18_10-28.csv"),
  descriptions = c("criteria (main criteria)",
                   "environmental sub-criteria",
                   "social sub-criteria",
                   "economic sub-criteria")
)

func_render_md_tables(df_csvInputFiles_CA,
                      "File table for city administrations")
```

Table 5: File table for city administrations

file_idx	keys	filenames	descriptions
1	crit	rdata_CA_crit_AHP_edible_Cities_2022-03-18_10-28.csv	criteria (main criteria)
2	env	rdata_CA_env_AHP_edible_Cities_2022-03-18_10-28.csv	environmental sub-criteria
3	soc	rdata_CA_soc_AHP_edible_Cities_2022-03-18_10-28.csv	social sub-criteria
4	eco	rdata_CA_eco_AHP_edible_Cities_2022-03-18_10-28.csv	economic sub-criteria

4.4.3 File table for non-governmental organizations

[33]:
```
df_csvInputFiles_NGO <- data.table(
  file_idx = 1:4,
  keys = c("crit", "env", "soc", "eco"),
  filenames = c("rdata_NGO_crit_AHP_edible_Cities_2022-03-18_10-40.csv",
                "rdata_NGO_env_AHP_edible_Cities_2022-03-18_10-40.csv",
                "rdata_NGO_soc_AHP_edible_Cities_2022-03-18_10-40.csv",
                "rdata_NGO_eco_AHP_edible_Cities_2022-03-18_10-40.csv"),
  descriptions = c("criteria (main criteria)",
                   "environmental sub-criteria",
                   "social sub-criteria",
                   "economic sub-criteria")
)

func_render_md_tables(df_csvInputFiles_NGO,
                      "File table for non-governmental organizations")
```

Table 6: File table for non-governmental organizations

file_idx	keys	filenames	descriptions
1	crit	rdata_NGO_crit_AHP_edible_Cities_2022-03-18_10-40.csv	criteria (main criteria)
2	env	rdata_NGO_env_AHP_edible_Cities_2022-03-18_10-40.csv	environmental sub-criteria
3	soc	rdata_NGO_soc_AHP_edible_Cities_2022-03-18_10-40.csv	social sub-criteria
4	eco	rdata_NGO_eco_AHP_edible_Cities_2022-03-18_10-40.csv	economic sub-criteria

4.4.4 File table for practitioners and experts

[34]:
```
df_csvInputFiles_PE <- data.table(
  file_idx = 1:4,
  keys = c("crit", "env", "soc", "eco"),
  filenames = c("rdata_PE_crit_AHP_edible_Cities_2022-03-18_10-41.csv",
                "rdata_PE_env_AHP_edible_Cities_2022-03-18_10-41.csv",
                "rdata_PE_soc_AHP_edible_Cities_2022-03-18_10-41.csv",
                "rdata_PE_eco_AHP_edible_Cities_2022-03-18_10-41.csv"),
  descriptions = c("criteria (main criteria)",
                   "environmental sub-criteria",
                   "social sub-criteria",
                   "economic sub-criteria")
)

func_render_md_tables(df_csvInputFiles_PE,
                      "File table for practitioners and experts")
```

Table 7: File table for practitioners and experts

file_idx	keys	filenames	descriptions
1	crit	rdata_PE_crit_AHP_edible_Cities_2022-03-18_10-41.csv	criteria (main criteria)
2	env	rdata_PE_env_AHP_edible_Cities_2022-03-18_10-41.csv	environmental sub-criteria

file_idx	keys	filenames	descriptions
3	soc	rdata_PE_soc_AHP_edible_Cities_2022-03-18_10-41.csv	social sub-criteria
4	eco	rdata_PE_eco_AHP_edible_Cities_2022-03-18_10-41.csv	economic sub-criteria

4.5 Visualize datasets of survey with package `ahpsurvey` for each group of participants

4.5.1 All participants

[35]:
```
func_process_ahpsurvey(df_csvInputFiles_all, "all", str_input_path_ahp,
                       str_output_path_ahp, df_attributes_labels)
```

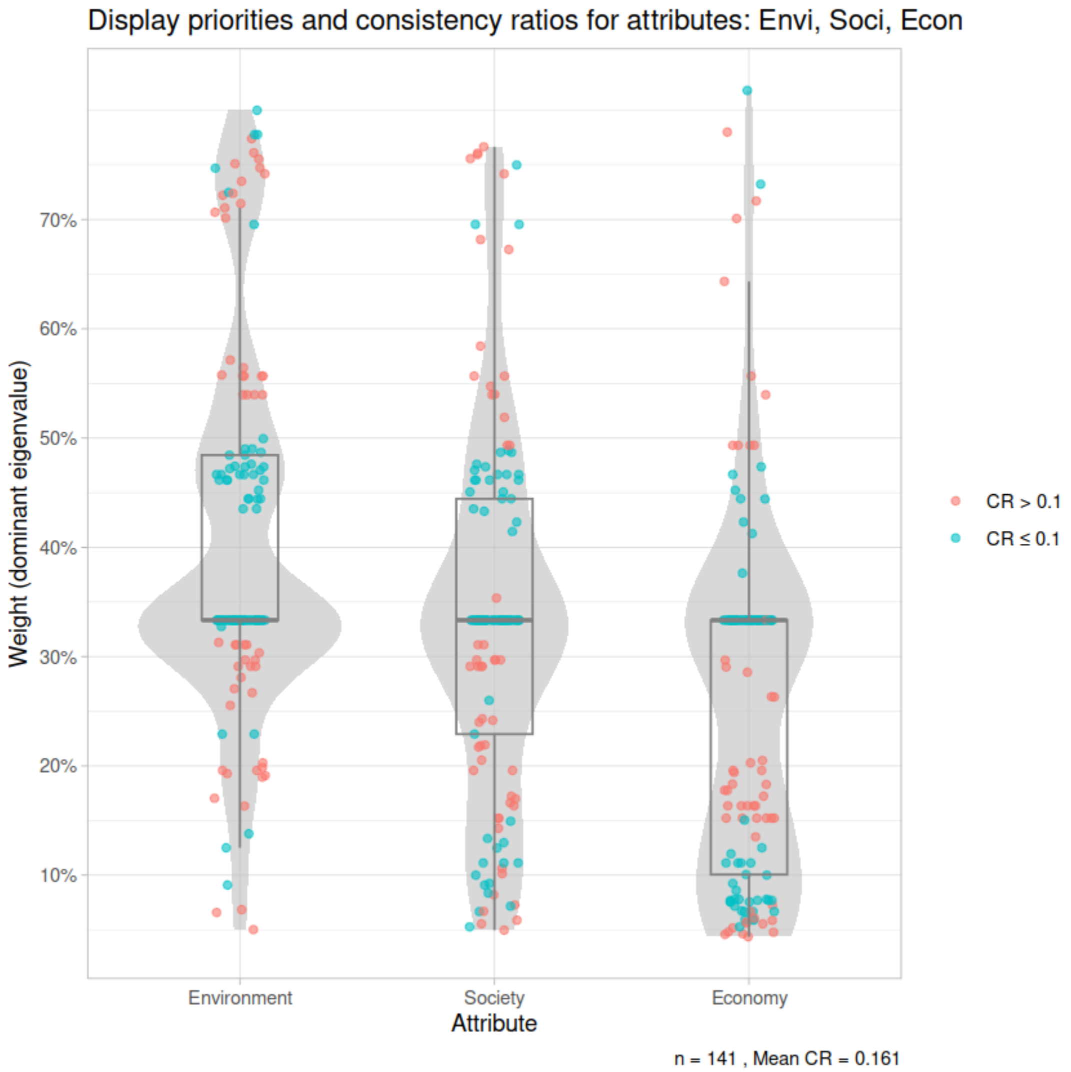

Figure 2: Series of violin plots that display the priorities and consistency ratios of all participants

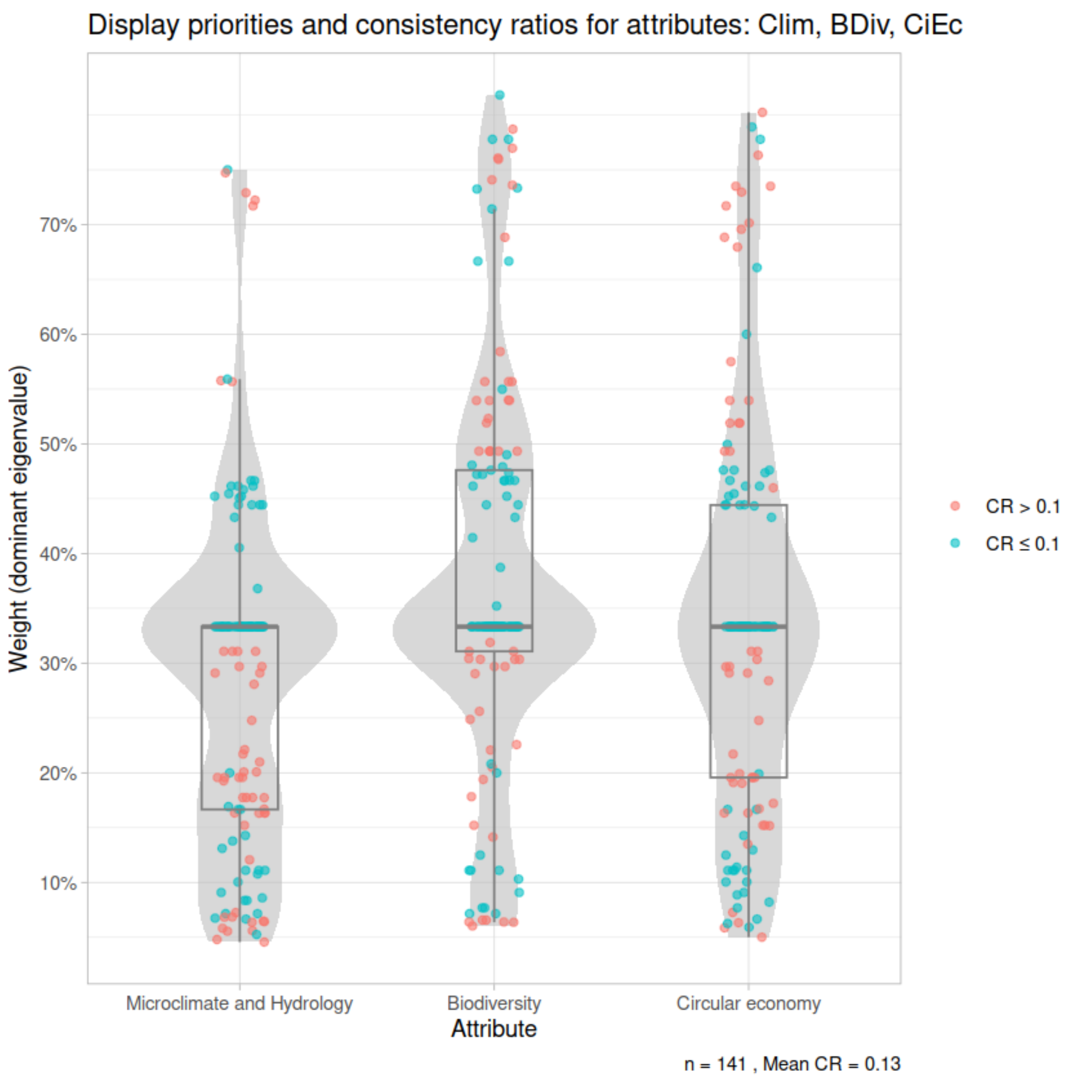

Figure 3: Series of violin plots that display the priorities and consistency ratios of all participants

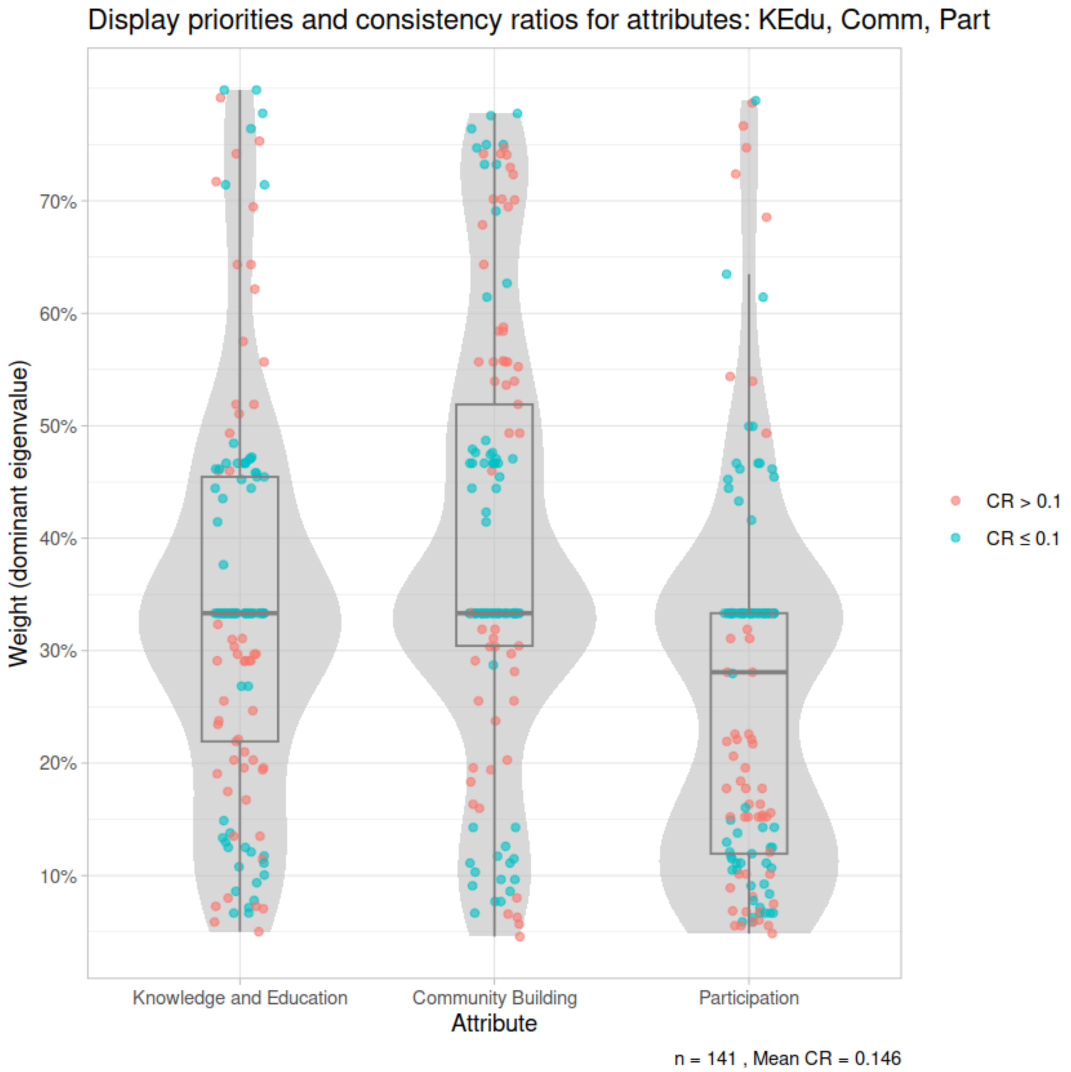

Figure 4: Series of violin plots that display the priorities and consistency ratios of all participants

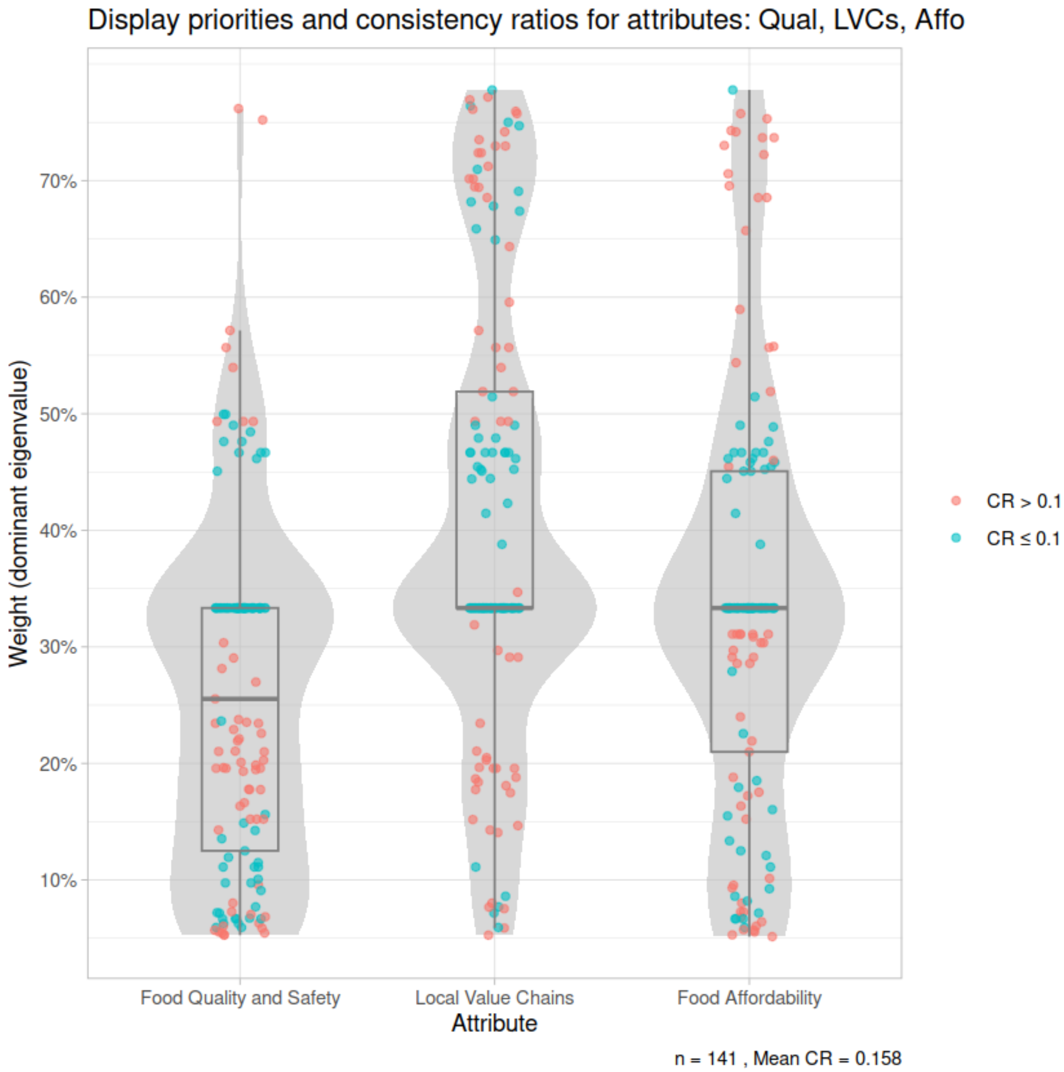

Figure 5: Series of violin plots that display the priorities and consistency ratios of all participants

4.5.2 Participants of city administrations

[36]:
```
func_process_ahpsurvey(df_csvInputFiles_CA, "CA", str_input_path_ahp,
                       str_output_path_ahp, df_attributes_labels)
```

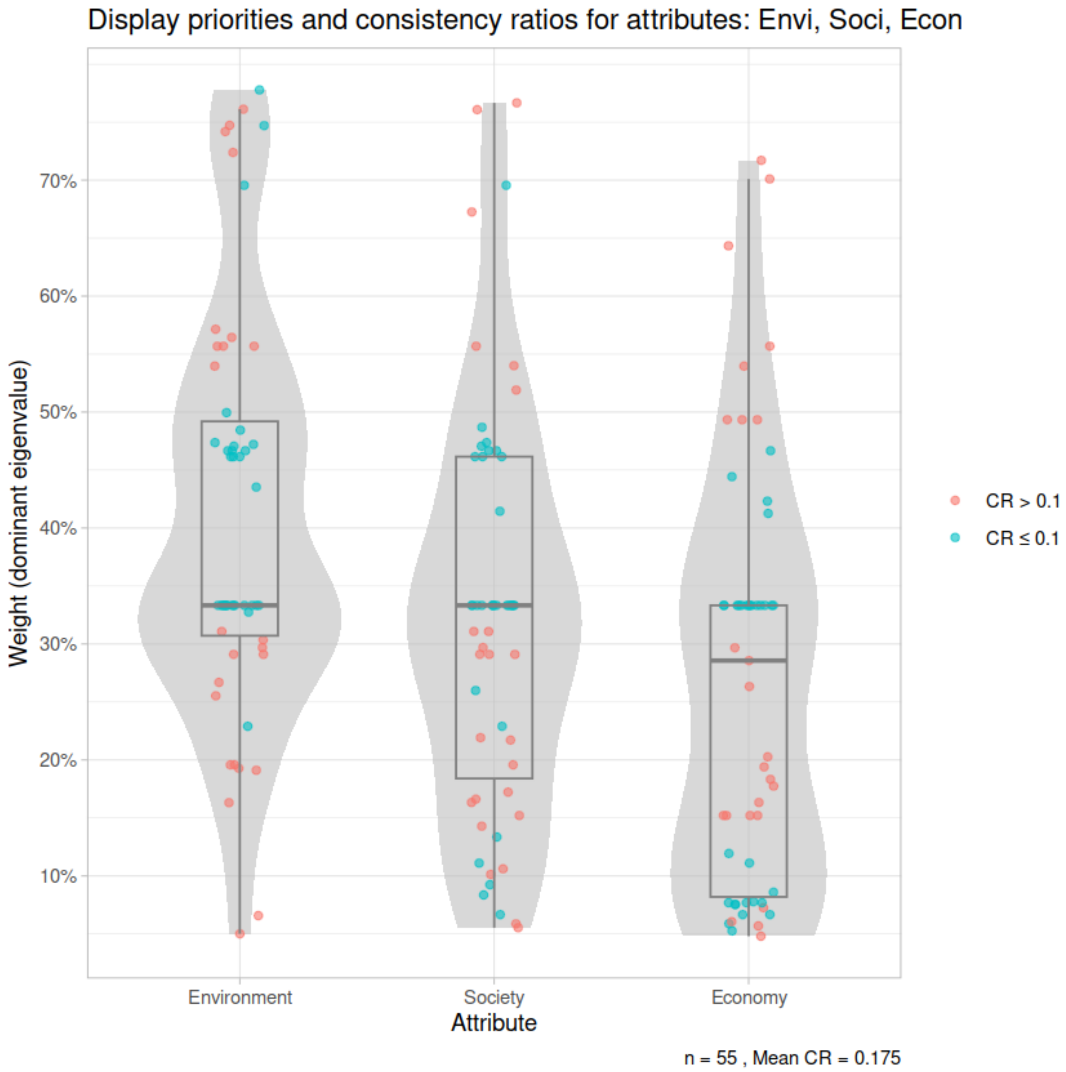

Figure 6: Series of violin plots that display the priorities and consistency ratios of city administrations

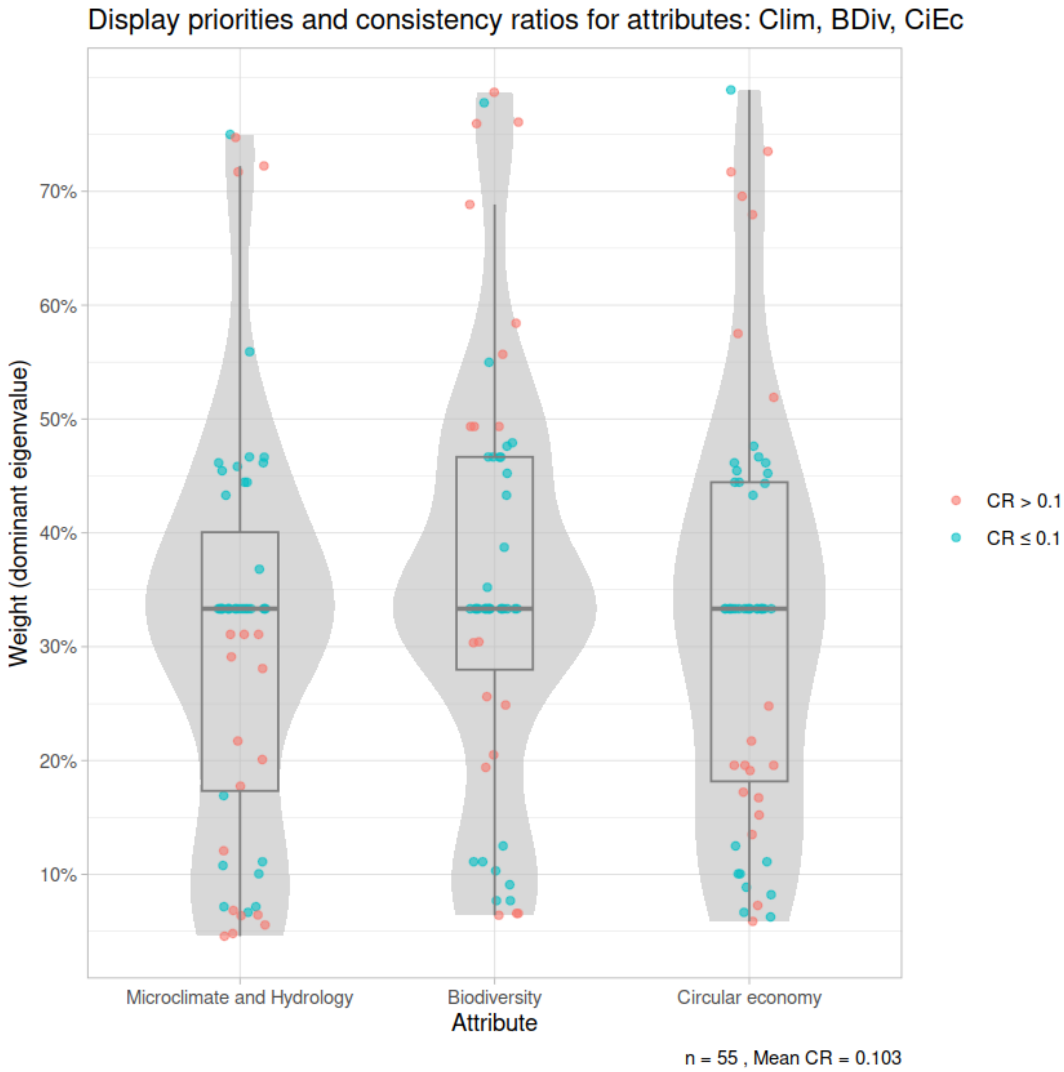

Figure 7: Series of violin plots that display the priorities and consistency ratios of city administrations

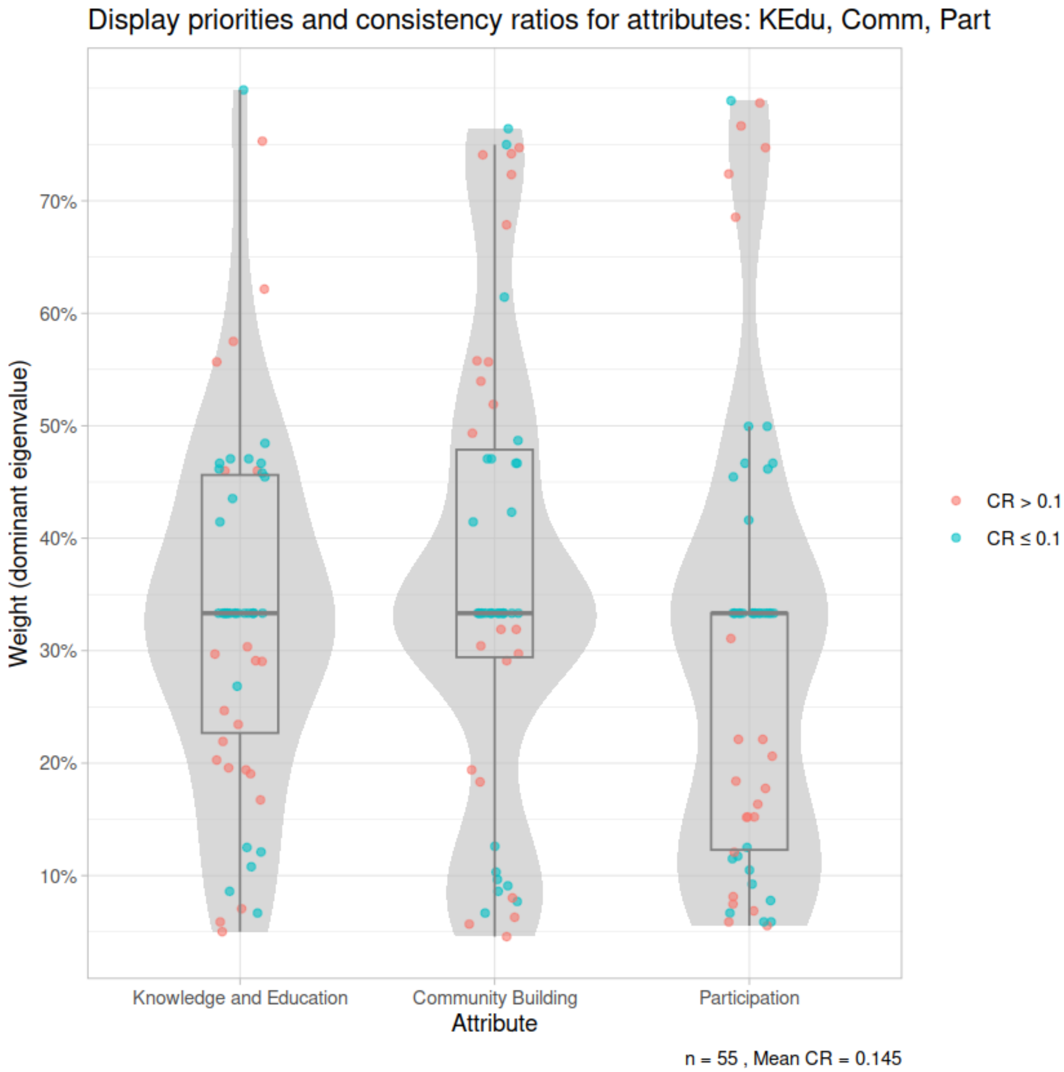

Figure 8: Series of violin plots that display the priorities and consistency ratios of city administrations

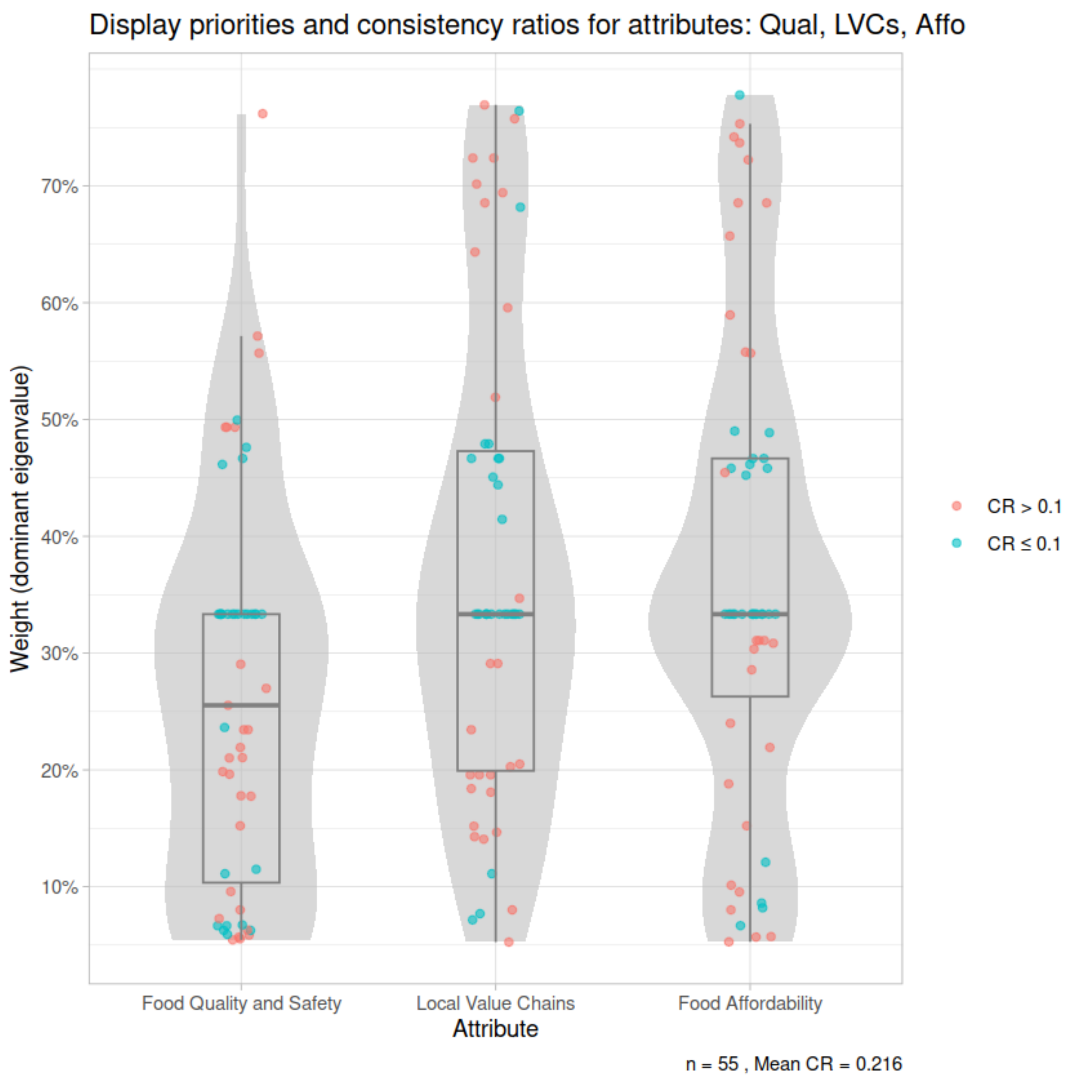

Figure 9: Series of violin plots that display the priorities and consistency ratios of city administrations

4.5.3 Participants of non-governmental organizations

[37]:
```
func_process_ahpsurvey(df_csvInputFiles_NGO, "NGO", str_input_path_ahp,
                       str_output_path_ahp, df_attributes_labels)
```

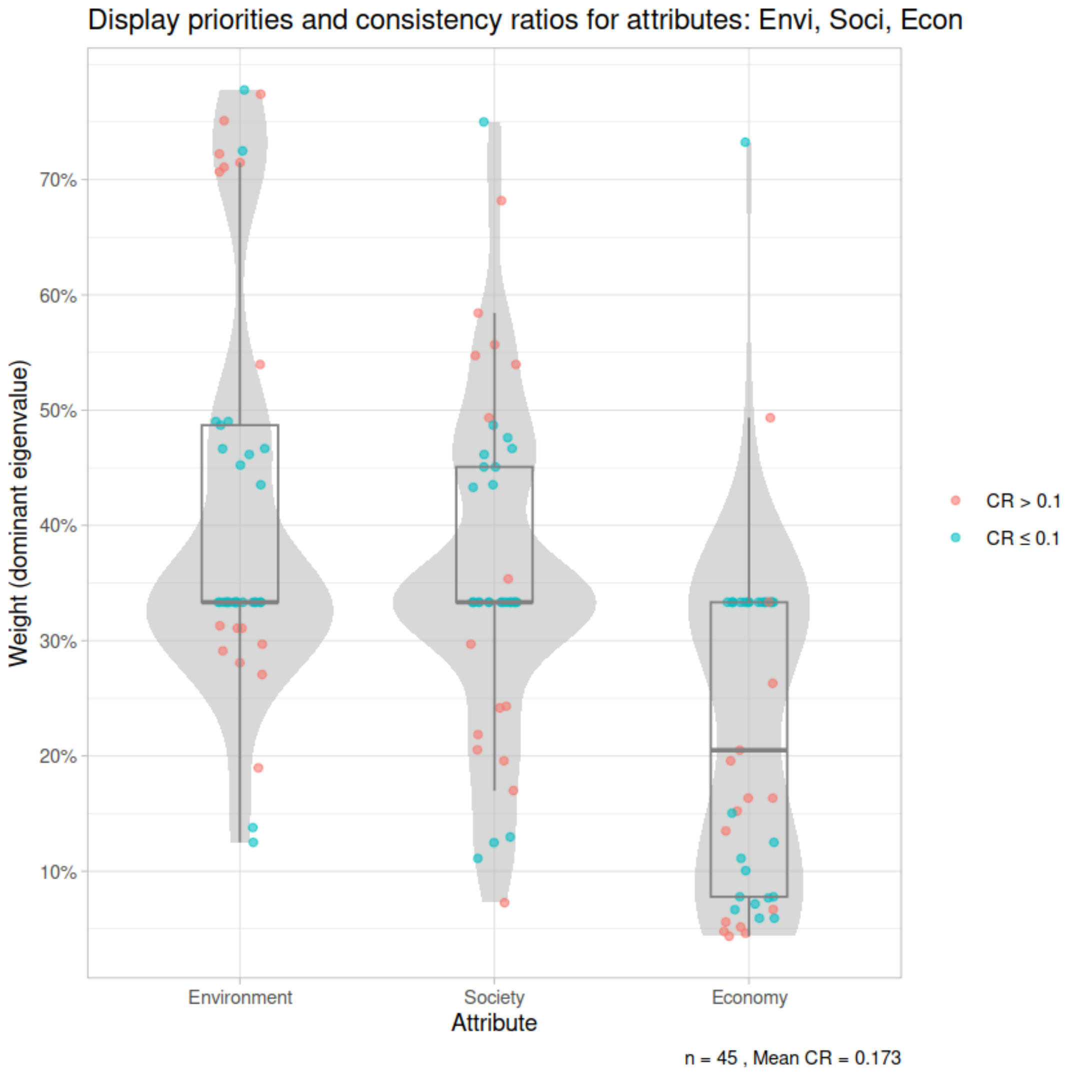

Figure 10: Series of violin plots that display the priorities and consistency ratios of non-governmental organizations

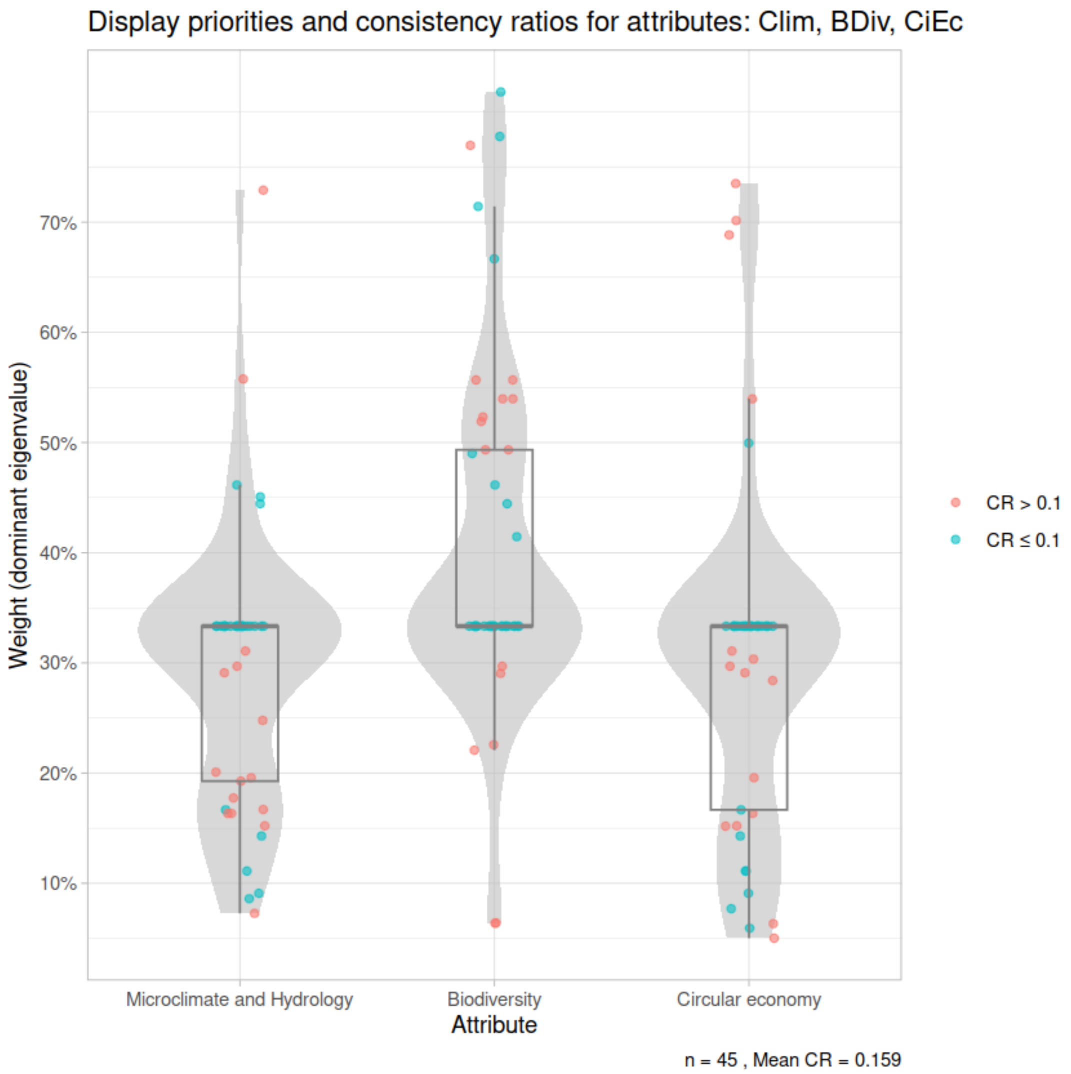

Figure 11: Series of violin plots that display the priorities and consistency ratios of non-governmental organizations

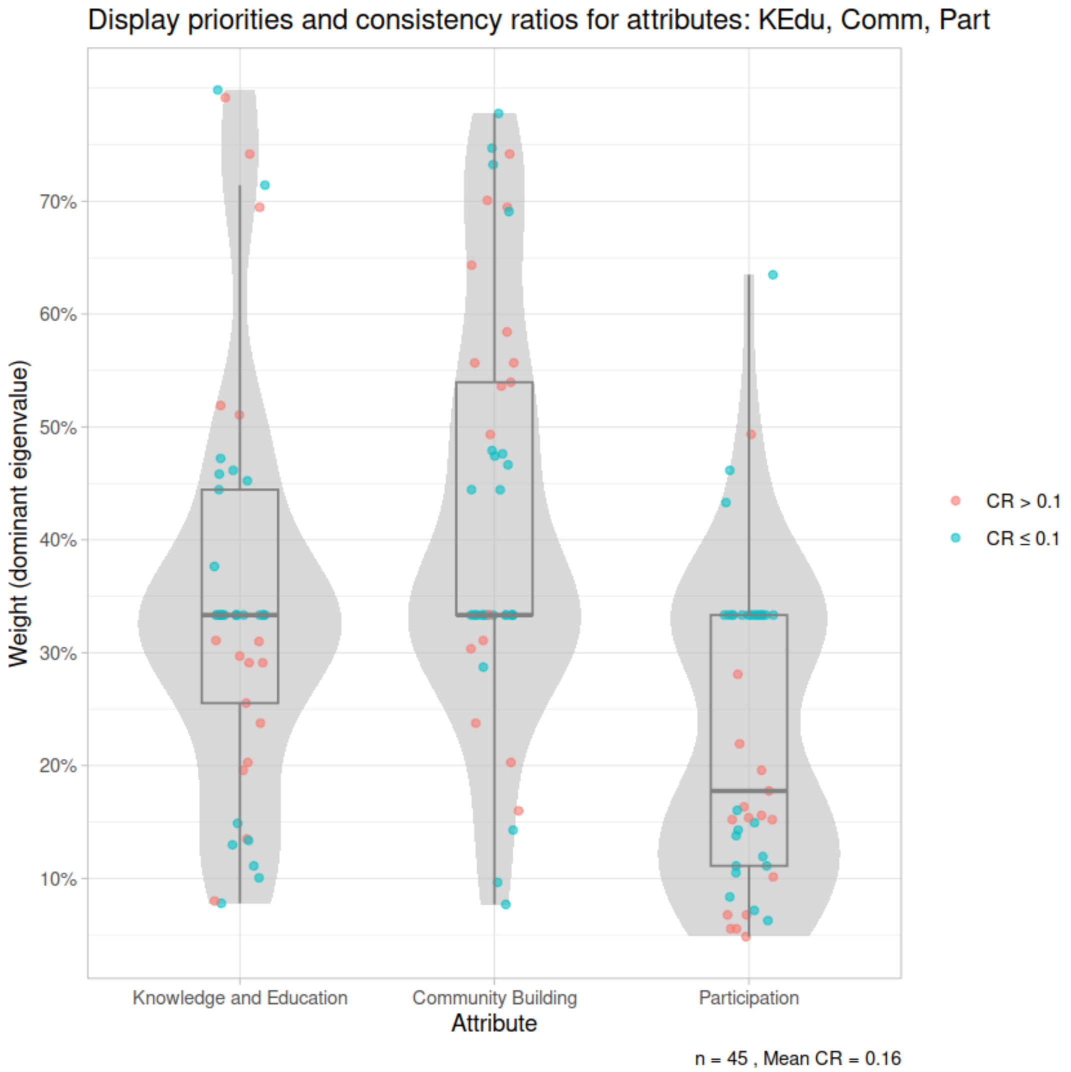

Figure 12: Series of violin plots that display the priorities and consistency ratios of non-governmental organizations

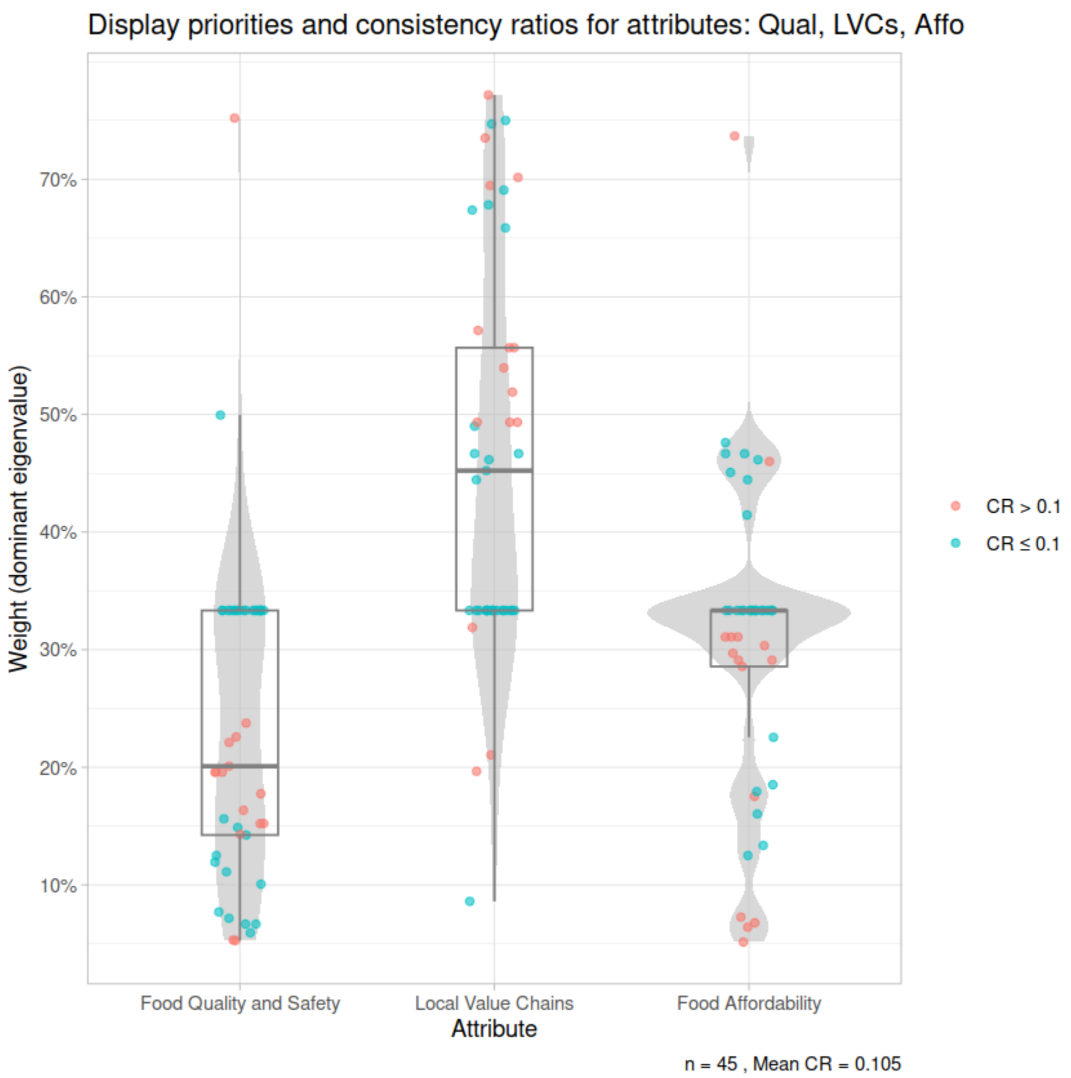

Figure 13: Series of violin plots that display the priorities and consistency ratios of non-governmental organizations

4.5.4 Participants of practitioners and experts

[38]:
```
func_process_ahpsurvey(df_csvInputFiles_PE, "PE", str_input_path_ahp,
                       str_output_path_ahp, df_attributes_labels)
```

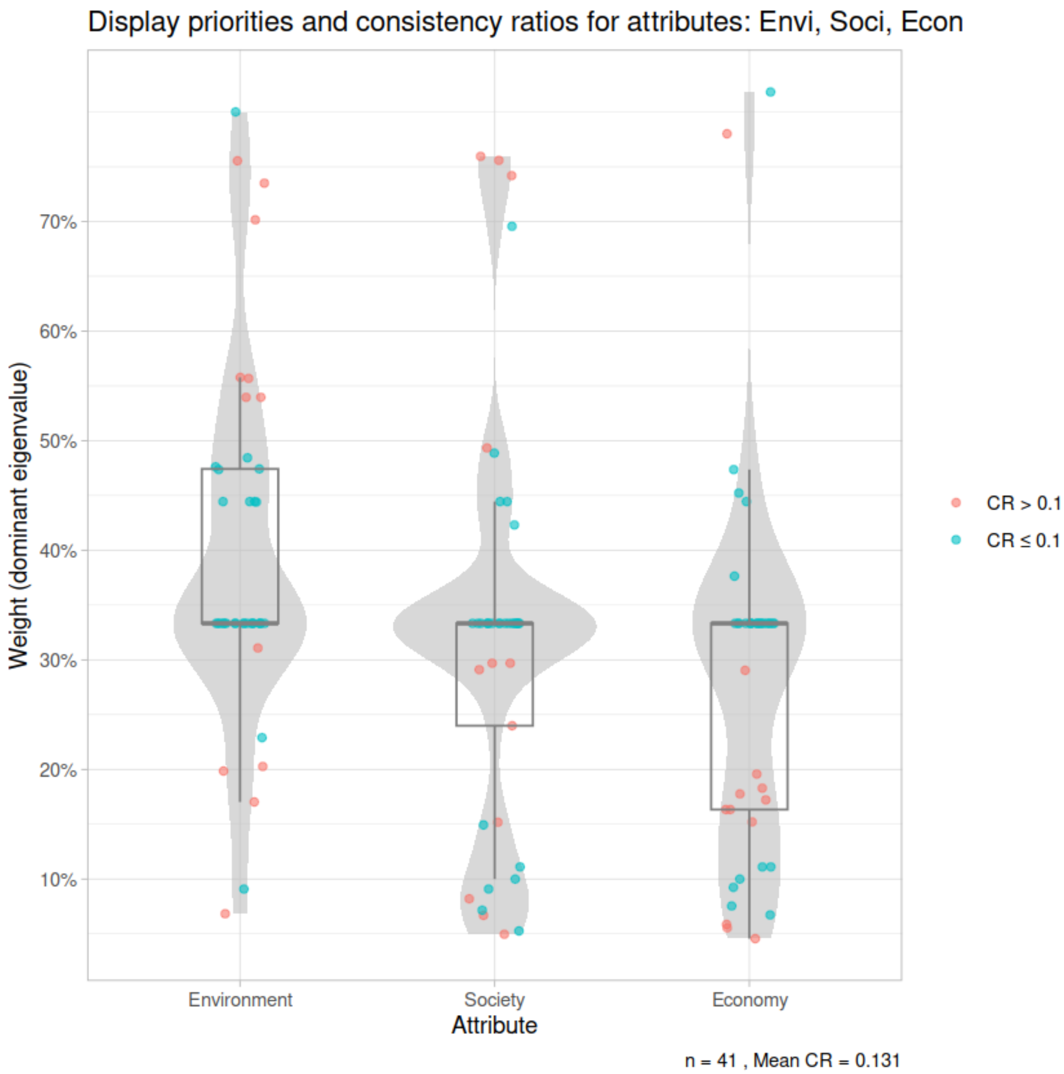

Figure 14: Series of violin plots that display the priorities and consistency ratios of practitioners and experts

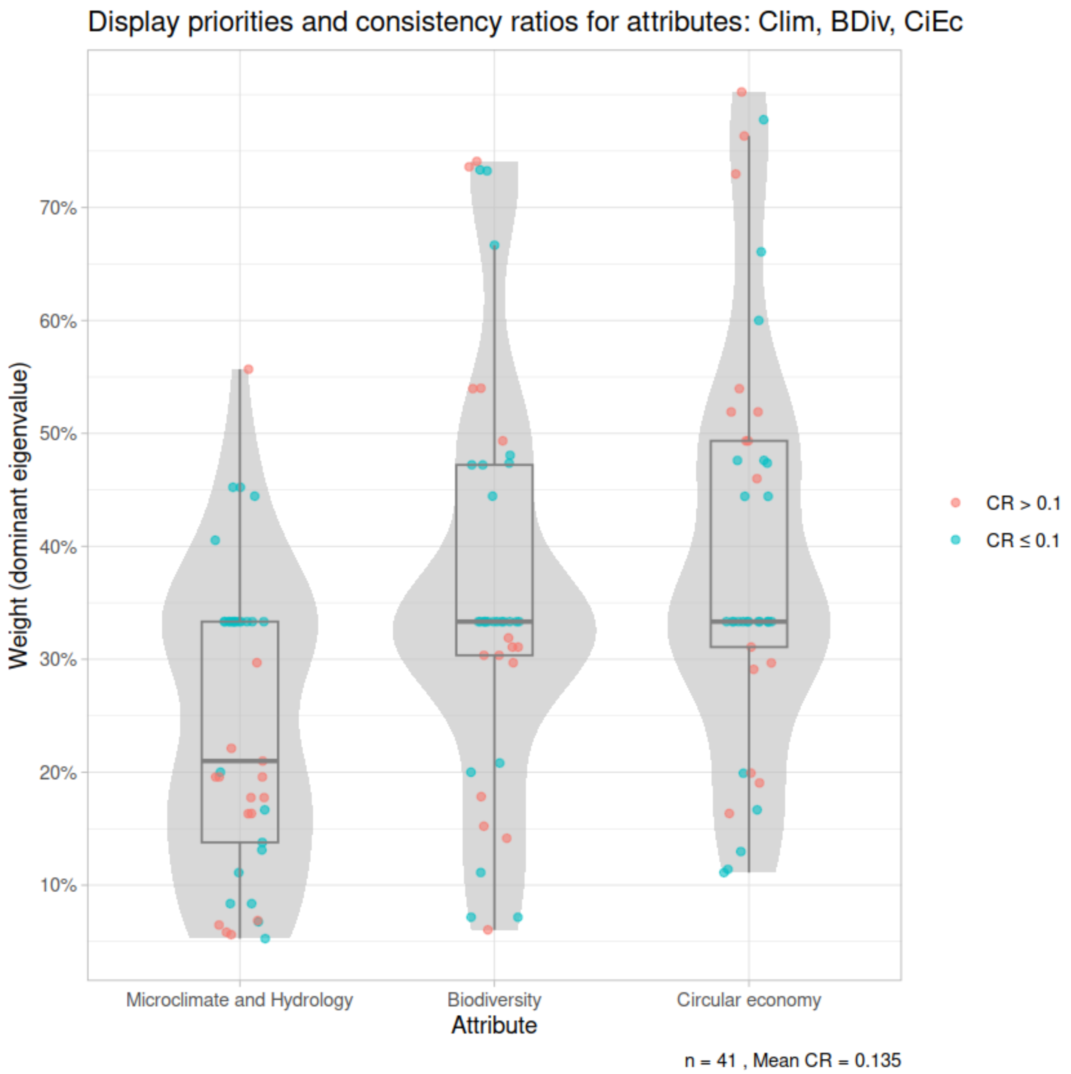

Figure 15: Series of violin plots that display the priorities and consistency ratios of practitioners and experts

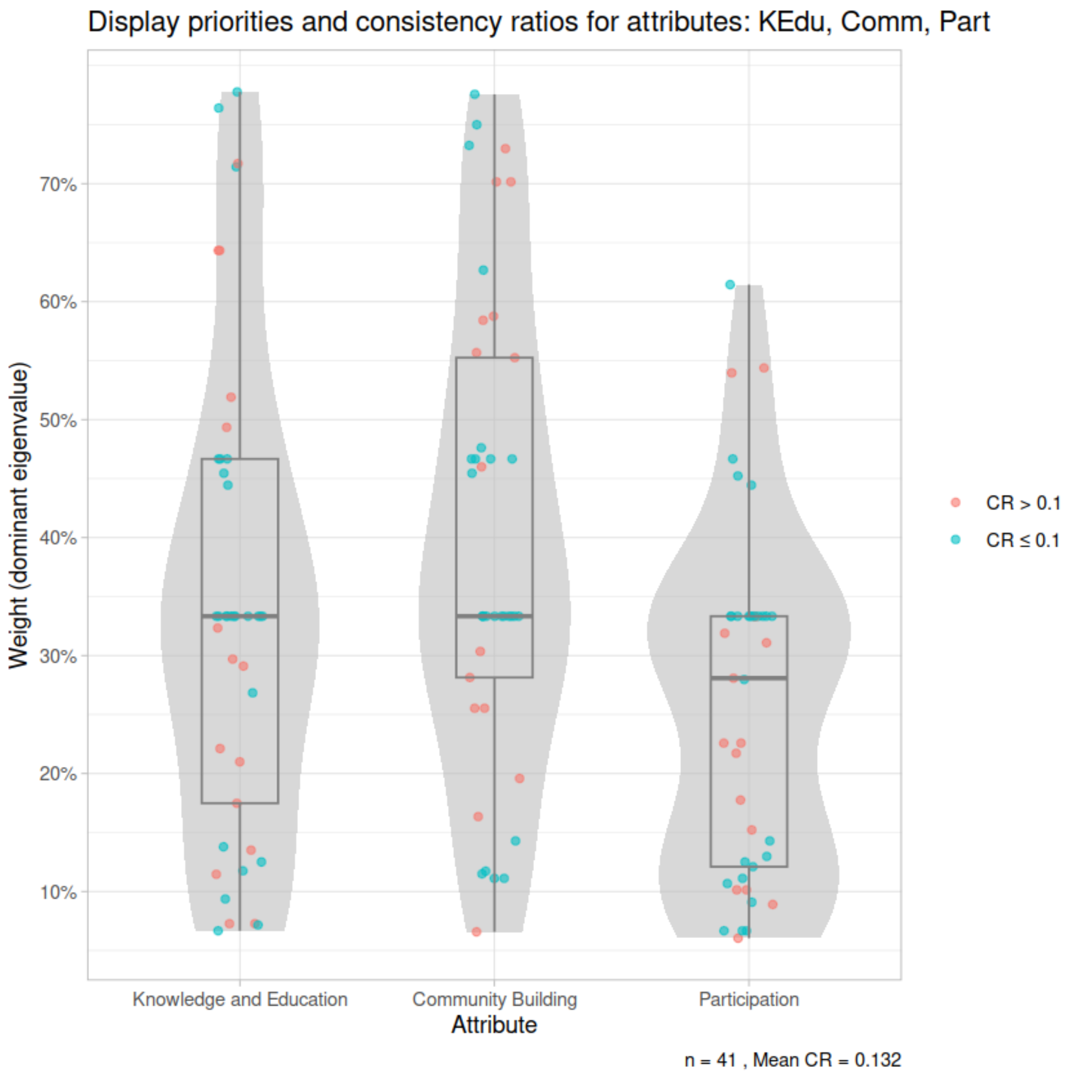

Figure 16: Series of violin plots that display the priorities and consistency ratios of practitioners and experts

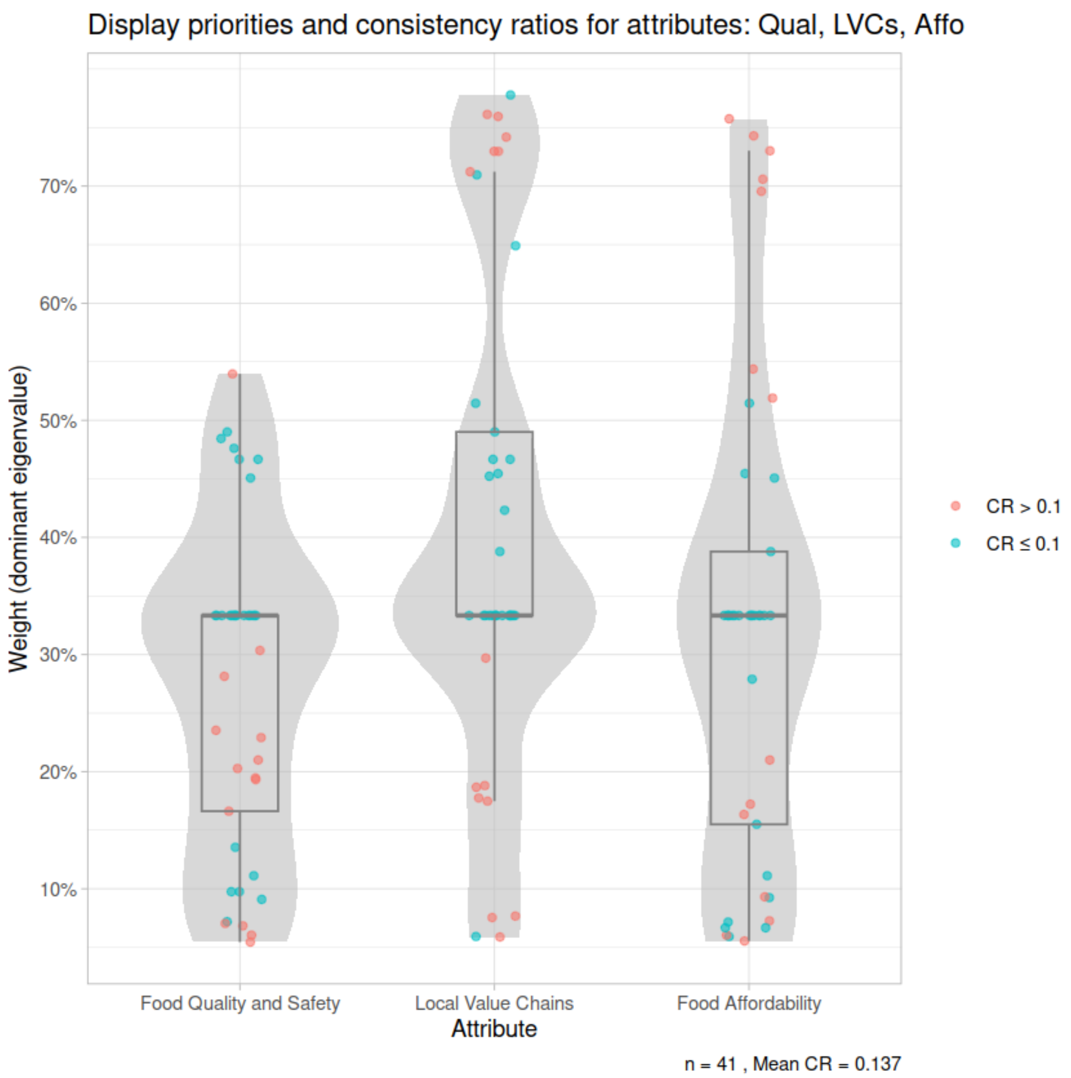

Figure 17: Series of violin plots that display the priorities and consistency ratios of practitioners and experts

4.6 Calculate aggregated preference weights for consistent datasets

[39]:
```
func_calc_pref_weights(df_csvInputFiles_all, str_input_path_ahp,
                       df_attributes_labels)
```

Table 8: Aggregated weights for criteria (main criteria)

	gmean.raw	gmean.norm
Envi	0.3739039	0.4179807
Soci	0.3023657	0.3380094
Econ	0.2182787	0.2440099
Sum	0.8945482	1.0000000

Table 9: Aggregated weights for environmental sub-criteria

	gmean.raw	gmean.norm	gmean.total
Clim	0.2741300	0.3089871	0.1291506
BDiv	0.3291718	0.3710277	0.1550824
CiEc	0.2838874	0.3199852	0.1337476
Sum	0.8871892	1.0000000	0.4179807

Table 10: Aggregated weights for social sub-criteria

	gmean.raw	gmean.norm	gmean.total
KEdu	0.3018698	0.3512801	0.1187360
Comm	0.3212634	0.3738480	0.1263641
Part	0.2362090	0.2748719	0.0929093
Sum	0.8593422	1.0000000	0.3380094

Table 11: Aggregated weights for economic sub-criteria

	gmean.raw	gmean.norm	gmean.total
Qual	0.2329901	0.2625724	0.0640703
LVCs	0.3666029	0.4131498	0.1008127
Affo	0.2877435	0.3242777	0.0791270
Sum	0.8873365	1.0000000	0.2440099

5 Summary and outlook

6 References

Online references

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Romer, Paul (Apr. 13, 2018). *Jupyter, Mathematica, and the Future of the Research Paper*. English. URL: https://paulromer.net/jupyter-mathematica-and-the-future-of-the-research-paper/ (visited on 09/08/2022) (cit. on p. 3).

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