1.2 ANOVA, analysis of variance

1.2.1 Method

Effects in experiments refer to the results or changes that occur as a result of manipulating factors. By detecting effects between independent variables or factors, it is possible to identify differences between the groups being compared. The presence or absence of meaningful effects is extremely important in determining, firstly, whether there is a cause and effect relationship between two independent variables and, secondly, whether the difference between the group means is different from each other.

ANOVA, known as analysis of variance, is a statistical method employed to determine if there are noteworthy differences in the means of two or more groups. It ensures that the observed effects are attributed to the independent variables by controlling experimental conditions.

The first step in any ANOVA analysis is to define the aim and purpose of the analysis. This includes identifying the independent variables, groups and outcome. A clear definition of the motivation for the analysis will help with the design of the experiment and the selection of the appropriate statistical tests, and it will also help with the formulation of hypotheses to be tested. It also helps to formulate the hypotheses to be tested and guide the subsequent steps of data collection, pre-processing and hypothesis testing to analyse the effects of the experiment. Since the aim of the analysis is the comparison of means between groups and the verification of the existence of a cause-effect relationship, the experimental design in our case appears to be a full factorial design. The reason for choosing this design is that all possible combinations of levels of the two independent variables are tested. In addition, each independent variable is manipulated at several levels. The more levels there are within each independent variable, the more groups there will be. It's also worth noting that this experimental design is carried out without a control group. By using a full factorial design, it is possible to detect main effects (= the effect of a given independent variable separately) as well as interaction effects (= the combined effects of the independent variables).

Once the experimental design has been identified, several pretests will be executed in order to test the equivalence between groups with explanatory variables such as age, gender, education level, income etc...

The second step helps to check whether the conditions of use are met or not. To do this, it is important to check for independence and to perform some tests for each group. In our case, the study appears to be a between-subjects design. The reason for this choice of design is that the study involves two manipulated factors (info_type, info_quantity). Each respondent is assigned to a specific combination of these factors. Therefore, different groups of respondents will experience different conditions. In addition, the respondent only experiences one level of the independent variable. As far as tests are concerned, here is a non-exhaustive list of tests that can be carried out (with their hypotheses):

Test of normality:

H0: the distribution is normal

H1: the distribution is not normal

Homogeneity of variances:

H0: there is a homogeneity of variances between experimental groups

H1: there is no homogeneity of variances between experimental groups (at least one different variances)

One of the critical steps in the analysis is the calculation of sums of squares. In this step, the total sum of squares (SST) is calculated first. This sum represents the differences between each observation and the mean. This score gives the variability of the variable. However, before this score is calculated, the factorial effects and the residual errors must be taken into account. The factorial effects represent the variation or influence of a factor on an independent variable. This effect is estimated by comparing the means for each modality. The factorial effect equation is as follows:

$$\mathrm{SCE_T} = \mathrm{SCE_F} + \mathrm{SCE_R}$$

In terms of residual error, it refers to the difference between the observed values of the variable and the values predicted by the model based on the independent variables. It is often considered as a measure of random error, capturing random influences and unexplained measurement errors. It is also worth noting that the residual error needs to be minimised as the observed differences between groups are more likely to be meaningful. Here is the equation that calculates the residual error:

$$SCE_R = \sum_{g=1}^{G} \sum_{a=1}^{ng} \left(Y_{ag} - \widehat{Y_g}\right)^2$$

As mentioned earlier, the total sum of squares represents the differences between each observation and the mean. This score is calculated from the sum of both the residual error and the factorial effect. Here is the equation:

$$SCE_F = \sum_{g=1}^{G} ng \left(Y_g - \hat{Y}\right)^2$$

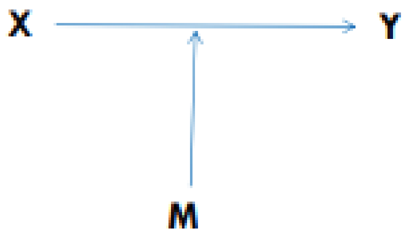
To identify the specific levels of the factor responsible for the effect, various post hoc tests can be used. One such post hoc test is the Tukey test, which allows for multiple pairwise comparisons. This test is used to validate one of the hypotheses and is used in this analysis to determine the effects of a given factor on an independent variable. On completion of the test, the result will confirm one of these hypotheses.

<u>Tuckey test</u>

H0: there is no significant difference between the means of the compared groups. In other words, all pairwise mean differences are equal to zero.

H1: there is a significant difference between at least one pair of group means. In other words, there is at least one pairwise mean difference that is not equal to zero.

In our case, the result of the aforementioned post-hoc test indicates whether or not there is a significant main/interaction effect, as we have chosen to conduct our study using the full factorial design. Here is a more visual way to see the effect of X (= a factor) on Y (= an independent variable). A moderator variable, marked M, has been added to check whether this moderator variable influences the relationship between the independent variable and the specified factor.



1.2.2 Results

Now that the methodology of ANOVA has been discussed, let's apply this analysis to our study. A software called SAS enterprise guide was used to carry out this analysis. The results and tables presented in this section are from this software. In terms of the variable to be analysed, there are three independent variables (= greener_change_intensity, value_information and decision_uncertainty). The aim of this section is to test the possible existence of the main effect of factor 1 (= info_type), the main effect of factor 2 (= info_quantity) and the interaction effect:

- on “Decision_uncertainty”
- on “Greener_change_intensity” (difference in level of CO2 chosen at visit 1 MINUS at visit 2)
- on “Value_information” (perceived value of footprint information)

But first, let's run some pretests on the groups. The purpose of pre-tests is to explore and understand the characteristics of each group and potentially guide the subsequent ANOVA analysis. The underline hypothesis being tested would normally focus on examining the independence or association between the categorical group variable and a given variable. In this case, because six groups were generated, tests are performed on groups based on variables like gender, age, education level, and income to test for associations between variables. Here are the hypotheses for each pre-test:

H0: There is no association or relationship between the group variable and the outcome variable.

H1: There is an association or relationship between the group variable and the outcome variable.

Regarding the gender pre-test of our six groups (see Figure 1, 2), in the data collection of our 421 respondents, two answers seem to be quite balanced. In each group, the number of men and women is quite similar. According to the chi-square probability, there is a 50.34% chance of being wrong if the null hypothesis is rejected. This means that the null hypothesis is chosen for this pre-test.

H0: There is no association or relationship between the group variable and the outcome variable.

H1: There is an association or relationship between the group variable and the outcome variable.

Table of Group by Q122					
	Q122				
Group	1	2	3	4	Total
1	42 49.41 21.00	40 47.06 18.87	0 0.00 0.00	3 3.53 42.86	85
2	36 44.44 18.00	44 54.32 20.75	1 1.23 50.00	0 0.00 0.00	81
3	35 54.69 17.50	29 45.31 13.68	0 0.00 0.00	0 0.00 0.00	64
4	32 45.07 16.00	37 52.11 17.45	0 0.00 0.00	2 2.82 28.57	71
5	25 41.67 12.50	35 58.33 16.51	0 0.00 0.00	0 0.00 0.00	60
6	30 50.00 15.00	27 45.00 12.74	1 1.67 50.00	2 3.33 28.57	60
Total	200	212	2	7	421

Figure 1 : The Table Analysis (group by gender)

Statistic	DF	Value	Prob
Chi-Square	15	14.2937	0.5034
Likelihood Ratio Chi-Square	15	17.2215	0.3058
Mantel-Haenszel Chi-Square	1	0.0943	0.7588
Phi Coefficient		0.1843	
Contingency Coefficient		0.1812	
Cramer's V		0.1064	
WARNING: 50% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Figure 2 : Table Analysis Test (group by gender)

The next pre-test examines the relationship between income and the group variables (see Appendix: Figure 3, 4). In each group, the majority of respondents either earned less than 19,999 euros per year or chose not to answer this question. Given the number of respondents who chose not to answer this question, the variable income doesn't seem to be a good indicator to classify the group. The Chi-square probability confirms our hypothesis as its value is 43.92%, which means that there is a 43.92% chance of being wrong by rejecting the null hypothesis. That's why the null hypothesis was chosen for this test:

H0: There is no association or relationship between the group variable and the outcome variable.

H1: There is an association or relationship between the group variable and the outcome variable.

The education level variable also appears to be independent. In fact, with a chi-square probability of 87.08%, it is clear that the null hypothesis must be selected (see Appendix: figure 5, 6). By rejecting the null hypothesis, there is an 87.08% chance of being wrong.

H0: There is no association or relationship between the group variable and the outcome variable.

H1: There is an association or relationship between the group variable and the outcome variable.

Finally, it also appears that there is no relationship between group and age (see Appendix: figure 7). The null hypothesis is chosen again, as rejecting the null hypothesis carries a 63.19% risk of being wrong.

H0: There is no association or relationship between the group variable and the outcome variable.

H1: There is an association or relationship between the group variable and the outcome variable.

Decision Uncertainty

As already mentioned in the Cronbach alpha and principal component analysis of the measurement scales, the independent variable decision_uncertainty is a computed variable composed of the results of questions 75-76-77 of the questionnaire and it provides information on how difficult it was for the respondents to make a decision between all the burgers proposed. This analysis tests the main effect of info_quantity or info_quality and the interaction effect of these factors.

Before interpreting the main and interaction effects on this independent variable, it is necessary to check two conditions of use in order to continue the analysis.

The normality test is a statistical test used to assess whether the data within each group or condition follow a normal distribution. The normality assumption in ANOVA implies that the residuals (the differences between the observed and predicted values) within each group are normally distributed. If the residuals are normally distributed, it suggests that the errors in the model are randomly distributed and the results of the ANOVA are more reliable. Two tests can be used to check the normality assumption, the Shapiro-Wilk test and the Kolmogorov-Smirnov test. Since the size of each group is more than fifty, the Kolmogorov-Smirnov test must be used to check the distribution. And with a p-value of less than 0.0001 (see figure X), there is less than a 0.0001% chance of being wrong in rejecting the null hypothesis. So the alternative hypothesis, which guarantees that the distribution in each group doesn't follow a normal distribution, is accepted. Although the distribution in all of our groups doesn't follow a normal distribution, the ANOVA analysis is quite robust to violations of the normality assumption, especially when the sample sizes are large.

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.830954	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.216049	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.795291	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	4.998987	Pr > A-Sq	<0.0050

Figure 8 : Test for Normality Table (decision uncertainty)

H0: the distribution is normal

H1: the distribution is not normal

Another extremely important test is Levene's test for homogeneity. Unlike the normality test, the assumption of homogeneous variances is crucial in ANOVA analysis. It ensures that the variability within each group is similar and that any observed differences between groups are not solely due to differences in variances. Violations of this assumption can lead to biased and unreliable ANOVA results. To perform this test, Levene's test checks whether either the null hypothesis or the alternative hypothesis needs to be accepted. A p-value of 0.0038% (see Figure X) provides a clear interpretation of the result. Since this p-value is less than 5%, rejecting the null hypothesis carries a 0.0038% risk of being wrong. The null hypothesis is rejected.

Levene's Test for Homogeneity of Decision_uncertainty Variance ANOVA of Absolute Deviations from Group Means					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Group	5	56.9602	11.3920	3.54	0.0038
Error	415	1336.0	3.2192		

Figure 9 : Levene's Test. For Homogeinity Table

H0: there is a homogeneity of variances between experimental groups

H1: there is no homogeneity of variances between experimental groups (at least one different variances)

Due to the lack of homogeneity of variances between experimental groups, there is no need to continue the ANOVA analysis to identify main or interaction effects of factors on the Decision_uncertainty variable.

Value information

Value_information is a variable responsible for measuring whether it is reliable and considered as quality information or not. It is a mixture of 4 items for the Q90-93. Regarding the test of normality (see Appendix: figure 10), the test used in this case is Kolmogorov-Smirnov, since the size for each group is greater than 50. The p-value of this test is less than 0.01%. This means that there is a 0.0038% risk that the null hypothesis is wrong. That's why the alternative hypothesis was chosen.

H0: the distribution is normal

H1: the distribution is not normal

The variance analysis is quite robust to the normality test. However, the result of the Levene's Test for Homogeneity is required. Here unfortunately, the p-value is 67.4% (see Appendix figure 11). Which means that the null hypothesis has been accepted.

H0: there is a homogeneity of variances between experimental groups

H1: there is no homogeneity of variances between experimental groups (at least one different variances)

Since the Levene's test for homogeneity has shown that the variances between the experimental groups are homogeneous, it is possible that there is a main effect of factor 1, a main effect of factor 2 or an interaction effect between factor 1 and factor 2. Regarding the main effect, the p-value of the main effect for info_type is 56.7% and the p-value of the main effect for info_quantity is 44.6% (see Appendix: figure 12). This means that the effect for both factors is not significant. The same goes for the interaction effect, with a p-value of 28.8%. The observed result proves that the difference between the groups is not statistically significant and is probably due to chance alone. Therefore, the null hypothesis for the Tuckey test is that there is no significance between the means of the comparison groups for each effect.

H0: there is no significant difference between the means of the compared groups. In other words, all pairwise mean differences are equal to zero.

H1: there is a significant difference between at least one pair of group means. In other words, there is at least one pairwise mean difference that is not equal to zero.

Greneer_intensity_change

Greener_intensity_change is a variable related to the difference in the level of CO2 chosen at visit 1 minus visit 2. The analysis of variance is used to test whether there is either a main effect or an interaction effect of factor 1 and factor 2. When performing the normality test (see Appendix: figure 13), the p-value for Kolmogorov-Smirnov is less than 0.01%. This p-value indicates that there is no normal distribution. Therefore, the null hypothesis is rejected.

H0: the distribution is normal

H1: the distribution is not normal

To see if the variances are homogeneous, the Levene's test is performed. Here the result is nuanced. As the p-value is 9.4% (see Appendix: figure 14). There is a 9.4% chance of being wrong in rejecting the null hypothesis. Since the Levene's test is crucial in determining whether there is a main effect or an interaction effect between Factor 1 and Factor 2, the null hypothesis is accepted.

Two conclusions can be drawn from the Tukey test. Firstly, no main effect can be identified. With a p-value of 95.1% for info_type and 56.8% for info_quantity, this proves that no main effect can be identified (see Appendix: figure 15). It also seems that no interaction effect can be observed. Therefore, there is no significant difference between the means of the groups compared. The null hypothesis is accepted as all p-values are greater than 5%.

H0: there is no significant difference between the means of the compared groups. In other words, all pairwise mean differences are equal to zero.

H1: there is a significant difference between at least one pair of group means. In other words, there is at least one pairwise mean difference that is not equal to zero.

1.2.2 Discussions

On the three variables analyzed with the ANOVA analysis. No one seems to be influenced by type of information or the quantity of information. However it would be wise to use another analysis to deepen the influence of these factors on the decision uncertainty variable.

2. Appendices

Table of Group by Q124

	Q124							
Group	1	2	3	4	5	6	7	Total
1	26 30.59 17.57	16 18.82 21.33	4 4.71 13.33	4 4.71 18.18	1 1.18 12.50	2 2.35 66.67	32 37.65 23.70	85
2	31 38.27 20.95	14 17.28 18.67	5 6.17 16.67	3 3.70 13.64	0 0.00 0.00	0 0.00 0.00	28 34.57 20.74	81
3	23 35.94 15.54	11 17.19 14.67	4 6.25 13.33	3 4.69 13.64	3 4.69 37.50	0 0.00 0.00	20 31.25 14.81	64
4	26 36.62 17.57	17 23.94 22.67	8 11.27 26.67	4 5.63 18.18	1 1.41 12.50	1 1.41 33.33	14 19.72 10.37	71
5	25 41.67 16.89	4 6.67 5.33	7 11.67 23.33	4 6.67 18.18	1 1.67 12.50	0 0.00 0.00	19 31.67 14.07	60
6	17 28.33 11.49	13 21.67 17.33	2 3.33 6.67	4 6.67 18.18	2 3.33 25.00	0 0.00 0.00	22 36.67 16.30	60
Total	148	75	30	22	8	3	135	421

Figure 3 : Table Analysis (group by revenue)

Statistic	DF	Value	Prob
Chi-Square	30	30.5220	0.4392
Likelihood Ratio Chi-Square	30	33.3070	0.3094
Mantel-Haenszel Chi-Square	1	0.2519	0.6158
Phi Coefficient		0.2693	
Contingency Coefficient		0.2600	
Cramer's V		0.1204	
WARNING: 50% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Figure 4 : Table Analysis Test (group by age)

Table of Group by Q123									
	Q123								
Group	1	2	3	4	5	6	7	8	Total
1	2 2.35 40.00	20 23.53 19.23	13 15.29 17.33	23 27.06 20.35	20 23.53 21.51	2 2.35 18.18	1 1.18 33.33	4 4.71 23.53	85
2	1 1.23 20.00	23 28.40 22.12	10 12.35 13.33	22 27.16 19.47	17 20.99 18.28	3 3.70 27.27	0 0.00 0.00	5 6.17 29.41	81
3	1 1.56 20.00	16 25.00 15.38	13 20.31 17.33	19 29.69 16.81	11 17.19 11.83	2 3.13 18.18	1 1.56 33.33	1 1.56 5.88	64
4	1 1.41 20.00	15 21.13 14.42	14 19.72 18.67	17 23.94 15.04	19 26.76 20.43	1 1.41 9.09	0 0.00 0.00	4 5.63 23.53	71
5	0 0.00 0.00	16 26.67 15.38	12 20.00 16.00	20 33.33 17.70	7 11.67 7.53	3 5.00 27.27	0 0.00 0.00	2 3.33 11.76	60
6	0 0.00 0.00	14 23.33 13.46	13 21.67 17.33	12 20.00 10.62	19 31.67 20.43	0 0.00 0.00	1 1.67 33.33	1 1.67 5.88	60
Total	5	104	75	113	93	11	3	17	421

Figure 5 : Table Analysis (group by education level)

Statistic	DF	Value	Prob
Chi-Square	35	25.8157	0.8708
Likelihood Ratio Chi-Square	35	30.2831	0.6952
Mantel-Haenszel Chi-Square	1	0.1864	0.6660
Phi Coefficient		0.2476	
Contingency Coefficient		0.2404	
Cramer's V		0.1107	
WARNING: 50% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Figure 6 : Table Analysis Test (group by education level)

Statistic	DF	Value	Prob
Chi-Square	270	261.5929	0.6319
Likelihood Ratio Chi-Square	270	264.3215	0.5860
Mantel-Haenszel Chi-Square	1	1.3164	0.2512
Phi Coefficient		0.7911	
Contingency Coefficient		0.6204	
Cramer's V		0.3538	
WARNING: 94% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Figure 7 : Table Analysis Test (group by age)

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.929386	Pr < W	0.0002
Kolmogorov-Smirnov	D	0.116858	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.192913	Pr > W-Sq	0.0065
Anderson-Darling	A-Sq	1.579598	Pr > A-Sq	<0.0050

Figure 20 : Tests for Normality Table (Value information)

Levene's Test for Homogeneity of Value_information Variance ANOVA of Absolute Deviations from Group Means					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Group	5	19.3401	3.8680	0.63	0.6740
Error	415	2532.3	6.1019		

Figure 31 : Levene's Test. For Homogeinity Table (Value information)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Info_type	2	23.11376838	11.55688419	0.57	0.5678
Info_quantity	1	11.85795660	11.85795660	0.58	0.4461
Info_type*Info_quant	2	50.87905809	25.43952904	1.25	0.2882

Figure 42 : Tuckey Test Table (Value information)

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.702866	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.375615	Pr > D	<0.0100
Cramer-von Mises	W-Sq	1.953097	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	11.19392	Pr > A-Sq	<0.0050

Figure 53 : Tests for Normality Table (Greener change intensity)

Levene's Test for Homogeneity of Greener_change_intensity Variance ANOVA of Absolute Deviations from Group Means					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Group	5	3.4455	0.6891	1.90	0.0940
Error	415	150.9	0.3636		

Figure 64 : Levene's Test. For Homogeinity Table (Greener change intensity)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Info_type	2	0.14236717	0.07118358	0.05	0.9513
Info_quantity	1	0.46240943	0.46240943	0.32	0.5695
Info_type*Info_quant	2	4.81015906	2.40507953	1.69	0.1866

Figure 75 : Tuckey Test Table (Greener change intensity)