Università
degli Studi
di Padova

STATISTICAL LEARNING,
A.Y 2022/2023

AIR QUALITY PREDICTION

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INTRODUCTION

The quality of the air that we breath is a crucial aspect of everyday life.

Every year air pollution causes:

4 0 0 0 0 0

deaths in Europe

5 0 0 0 0

deaths in Italy

INTRODUCTION

Venice

PM10 AND AIR QUALITY

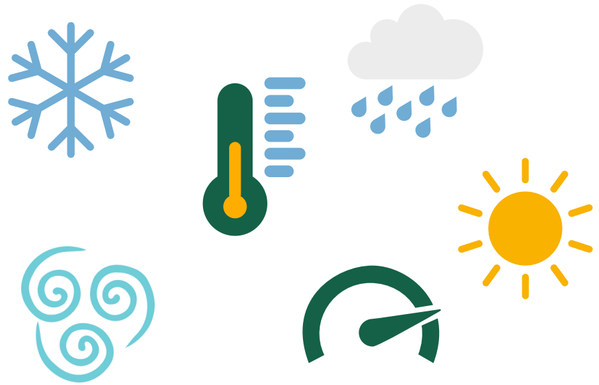
LIMIT	NUM/YEAR
50 µg/m3	35

TASK

Binary classification problem

TODAY —predict→ **TOMORROW**

Meteorological conditions



Air quality

PM10 < 50 µg/m3

PM10 >= 50 µg/m3

WHAT ARE THE ADVANTAGES?

SOCIAL ASSISTANCE

Helping people with health conditions to detect critical days and can avoid outdoor activities and take protective measures such as wearing masks

ECONOMIC

METEOROLOGICAL CONDITIONS	VS	PM10
• easy to measure • affordable • can be measure everywhere		• specialized equipment • expensive to mantain • sparsely distributed

GOALS

- **INTERPRETABILITY**

1. Can meteorological data be used to predict air quality?
2. What are the weather predictors that are significant to the forecast and what is their influence?

- **PREDICTION**

1. How do models perform in making forecasts?
    - Comparing performances using different metrics

OVERVIEW

01 DATASET CONSTRUCTION

02 DATA PREPROCESSING

03 EXPLORATORY DATA ANALYSIS

04 MODELS

05 CONCLUSIONS

DATASET CONSTRUCTION

WEATHER DATA

Agenzia Regionale per la Prevenzione
e Protezione Ambientale del Veneto

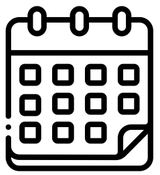
PM10 DATA

FINAL DATASET

WEATHER DATASETS

- Data from years: 2018,2019,2021, 2022
- 15 variables

Location



Date

T_min(˚C)
T_max(˚C)
T_med(˚C)

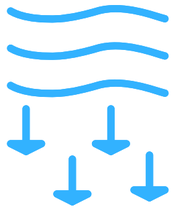
Dew Point(˚C)

Humidity

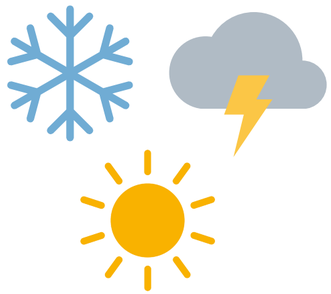
Visibility(km)

Rain(mm)

Wind_speed_med (km/h)
Wind_speed_max (km/h)
Gust(km/h)



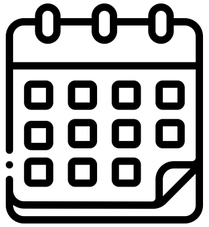
Pressure (mb)
Pressure_med (mb)



Phenomena
(fog, rain, snow,
thunderstorm...)

PM10 DATASETS

- 2 variables for years 2018 and 2022: Date and PM10
- For 2019 and 2021 datasets, from several stations, the selected ones are: Parco Bissuola (reference station) and Via Tagliamento.
- 3 variables for years 2019 and 2021



Date

PM10

- Parco Bissuola
- Via Tagliamento

DATA PREPROCESSING

1 HANDLE MISSING VALUES

WEATHER DATASETS

- Two days with missing values: 5/2/2019 and 14/1/2021
- Solution: median imputation considering the specific month and year

PM10 DATASETS

- The PM10 values of Parco Bissuola contain:
  - 1 NA value in 2018
  - 12 NA values in 2022
- Solution: consider the data that comes from the nearby station in Via Tagliamento

DATA PREPROCESSING

2 DATA CLEANING AND PREPARATION

```
##    Location            Date               T_med           T_max
##  Length:1460        Length:1460        Min.   :-3.00   Min.   :-4.0
##  Class :character   Class :character   1st Qu.: 7.00   1st Qu.: 4.0
##  Mode  :character   Mode  :character   Median :15.00   Median :11.0
##                                        Mean   :14.71   Mean   :10.8
##                                        3rd Qu.:22.00   3rd Qu.:18.0
##                                        Max.   :30.00   Max.   :27.0
##      T_min          Dew_point        Humidity       Visibility
##  Min.   :-2.00   Min.   : 0.00   Min.   :35.00   Min.   : 0.00
##  1st Qu.:11.00   1st Qu.: 4.00   1st Qu.:65.00   1st Qu.:15.00
##  Median :18.00   Median :10.00   Median :74.00   Median :19.00
##  Mean   :18.46   Mean   :10.16   Mean   :73.94   Mean   :16.75
##  3rd Qu.:26.00   3rd Qu.:16.00   3rd Qu.:84.00   3rd Qu.:20.00
##  Max.   :35.00   Max.   :24.00   Max.   :99.00   Max.   :24.00
##  Wind_speed_med  Wind_speed_max       Gust       Pressure     Pressure_med
##  Min.   : 4.00   Min.   :  5.00   Min.   :0   Min.   : 989   Min.   :0
##  1st Qu.: 8.00   1st Qu.: 15.00   1st Qu.:0   1st Qu.:1011   1st Qu.:0
##  Median :10.00   Median : 17.00   Median :0   Median :1015   Median :0
##  Mean   :10.76   Mean   : 19.36   Mean   :0   Mean   :1016   Mean   :0
##  3rd Qu.:12.00   3rd Qu.: 22.00   3rd Qu.:0   3rd Qu.:1020   3rd Qu.:0
##  Max.   :39.00   Max.   :100.00   Max.   :0   Max.   :1037   Max.   :0
##       Rain    Phenomena
##  Min.   :0   Length:1460
##  1st Qu.:0   Class :character
##  Median :0   Mode  :character
##  Mean   :0
##  3rd Qu.:0
##  Max.   :0
```

- Removal of unuseful covariates: Gust, Pressure_med, Rain, Location

DATA PREPROCESSING

2 DATA CLEANING AND PREPARATION

- Extraction of possible useful variables

Date → Year, Month, Day_of_week

- Encoding of categorical variables: Phenomena, Year, Month and Day_of_week

Initial levels Phenomena: 8 → Final levels Phenomena: 4

```
                                   nebbia              neve
           821                        156                 3
       pioggia             pioggia nebbia      pioggia neve
           293                         57                 2
pioggia temporale  pioggia temporale nebbia
           126                          2
```

```
No event     Fog
     824     156

    Rain   Storm
     352     128
```

DATA PREPROCESSING

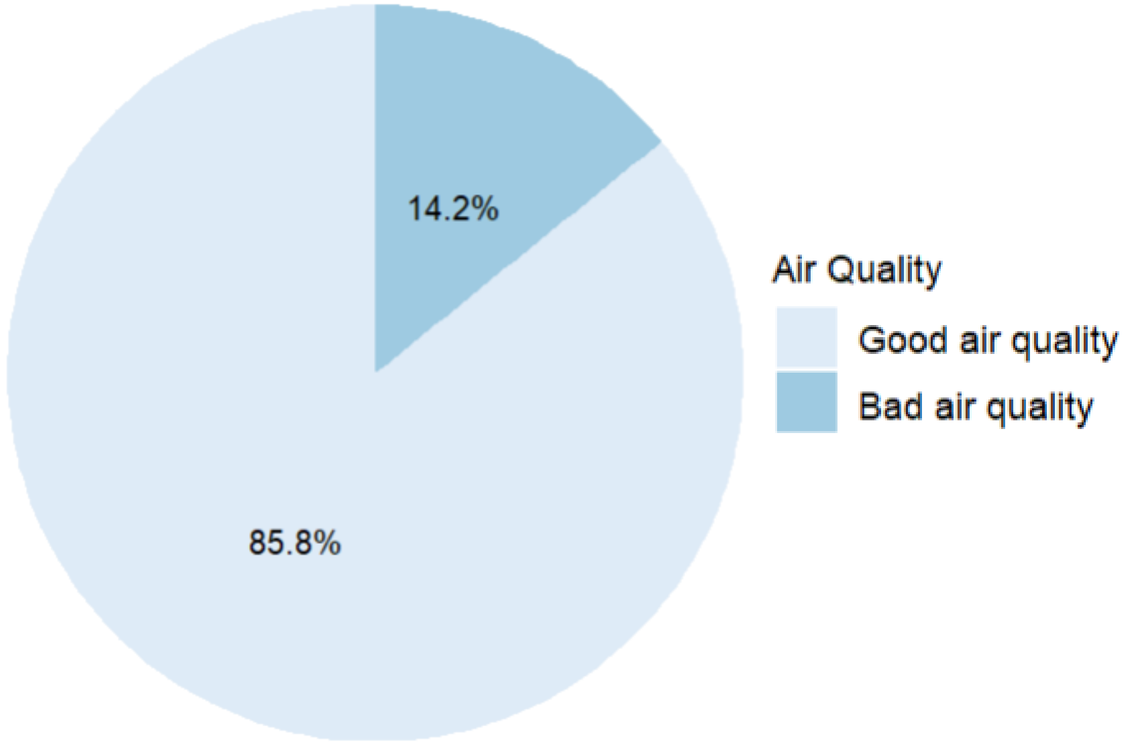
3 CLASS BALANCE CHECK

- The response binary variable **BadAirQuality** is created from the PM10 values of Parco Bissuola station

PM10 < 50 µg/m3

PM10 >= 50 µg/m3

- Imbalanced problem

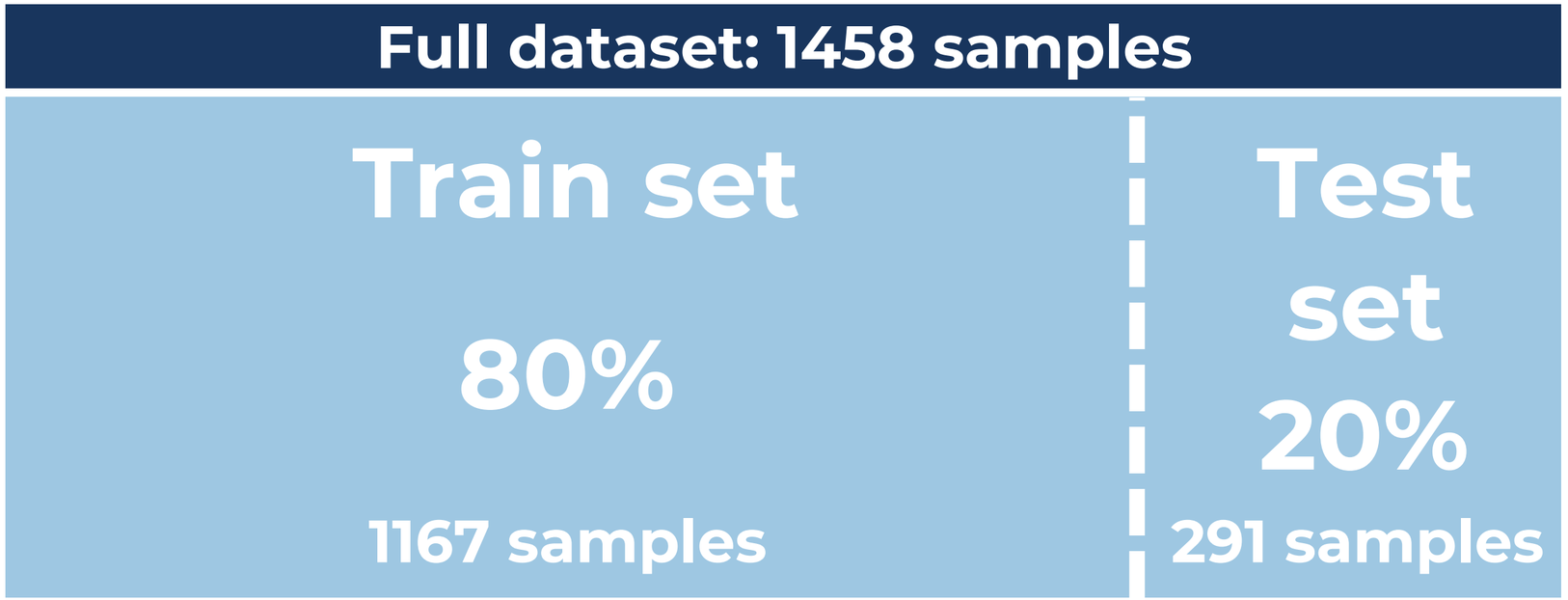


DATA PREPROCESSING

4

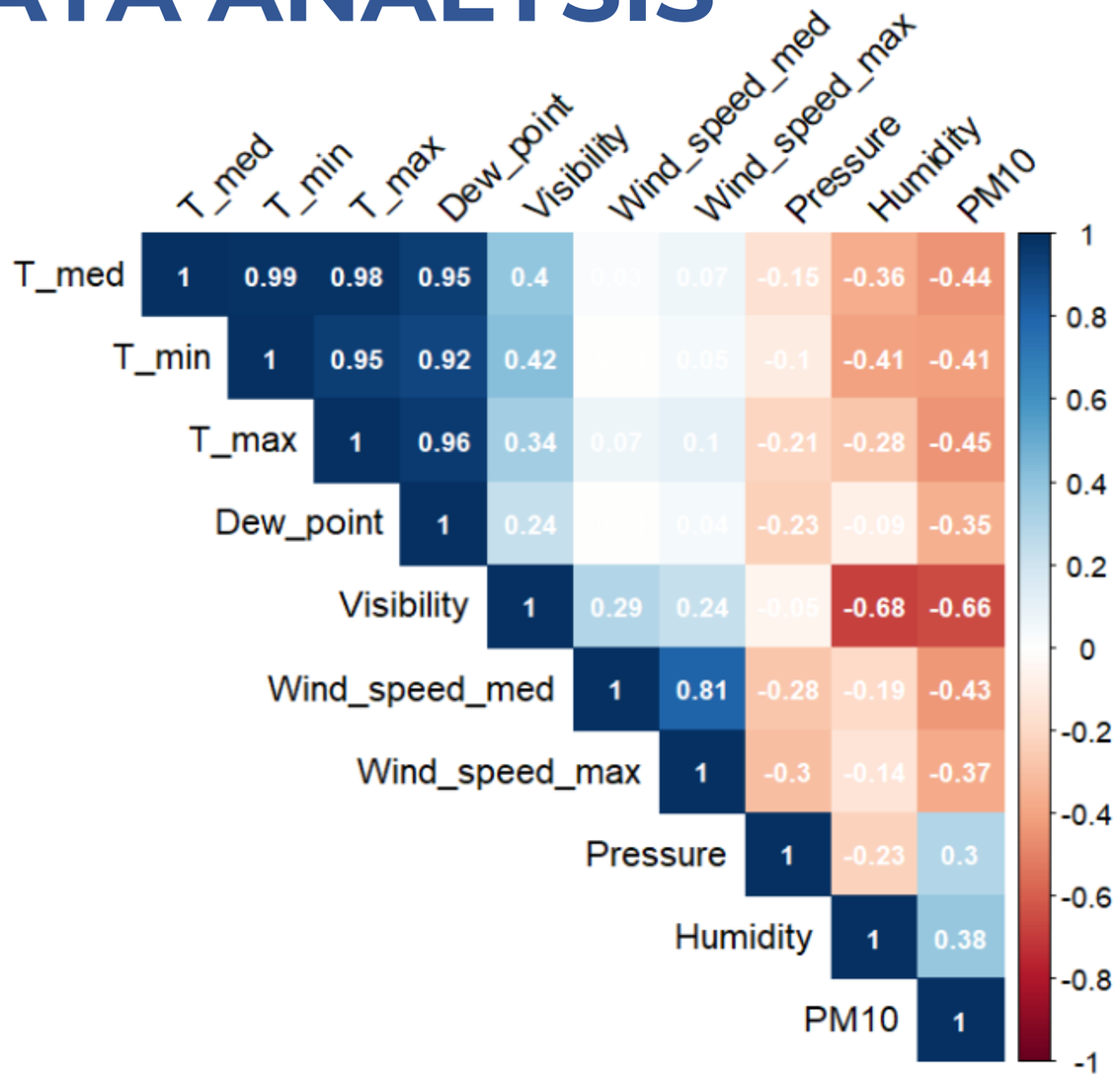
TRAIN-TEST SPLIT

The dataset is divided into training (80%) and testing (20%) in a stratified manner to respect the proportion of the two classes



EXPLANATORY DATA ANALYSIS

CORRELATION MATRIX

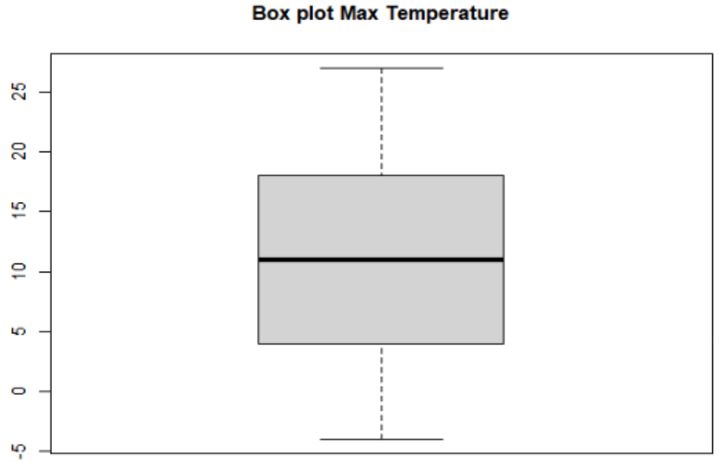


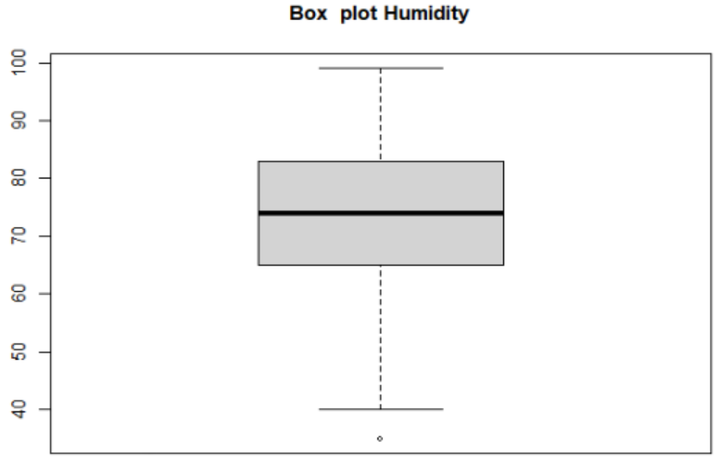
Removal of highly correlated variables based on the correlation with the response PM10.

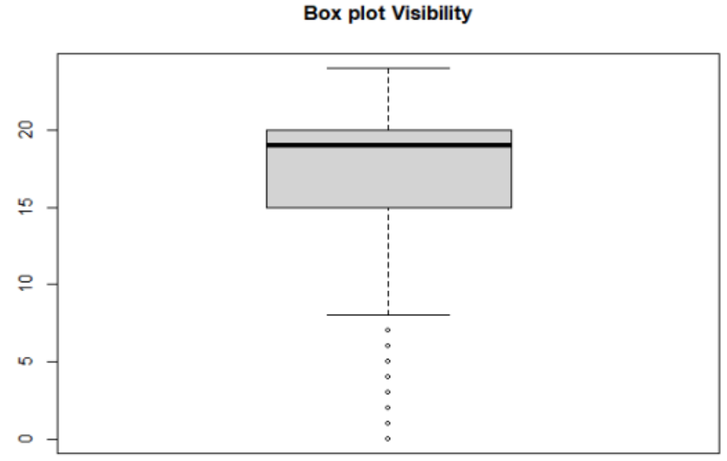
- T_min
- T_med
- Dew_point
- Wind_speed_max

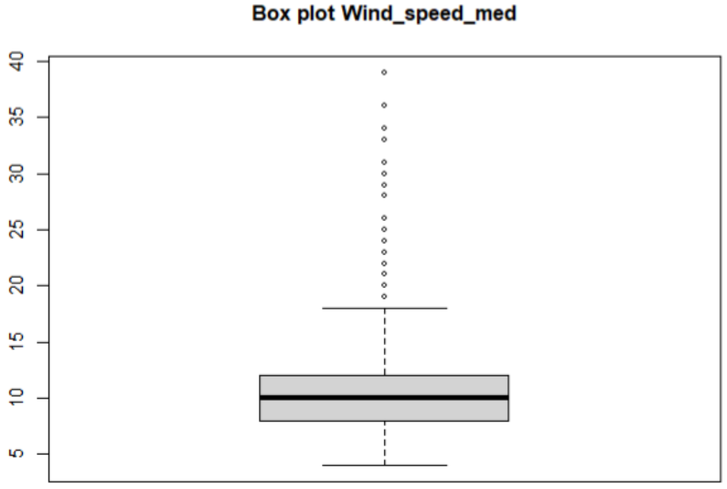
EXPLANATORY DATA ANALYSIS

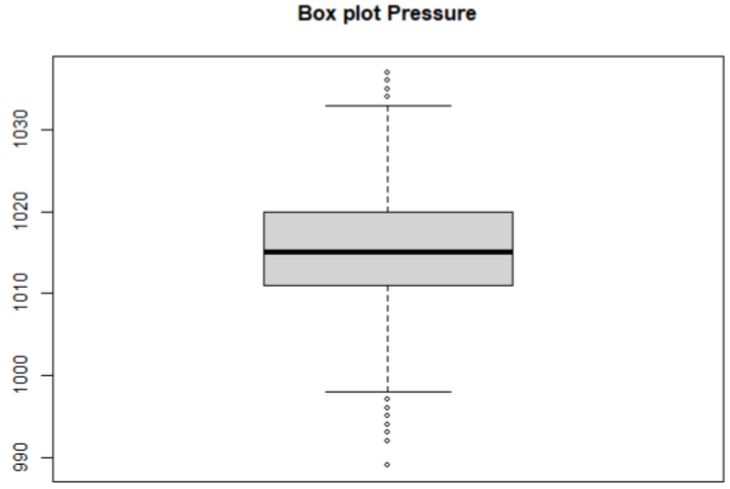
OUTLIERS





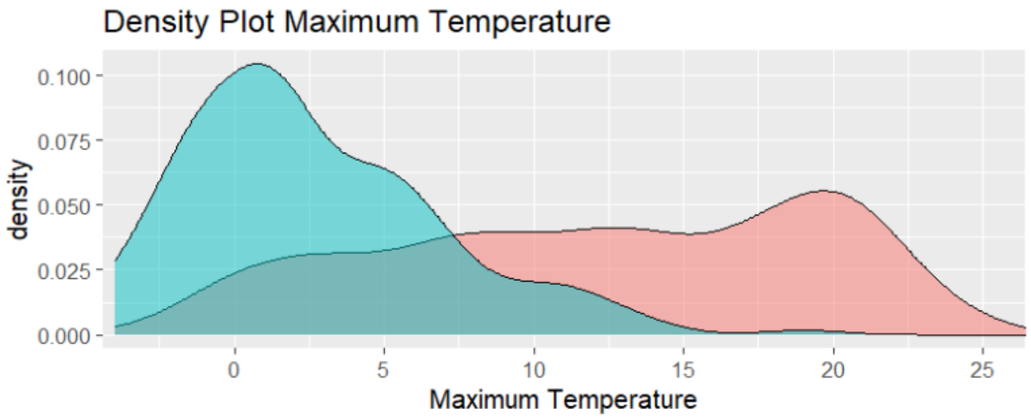


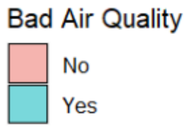


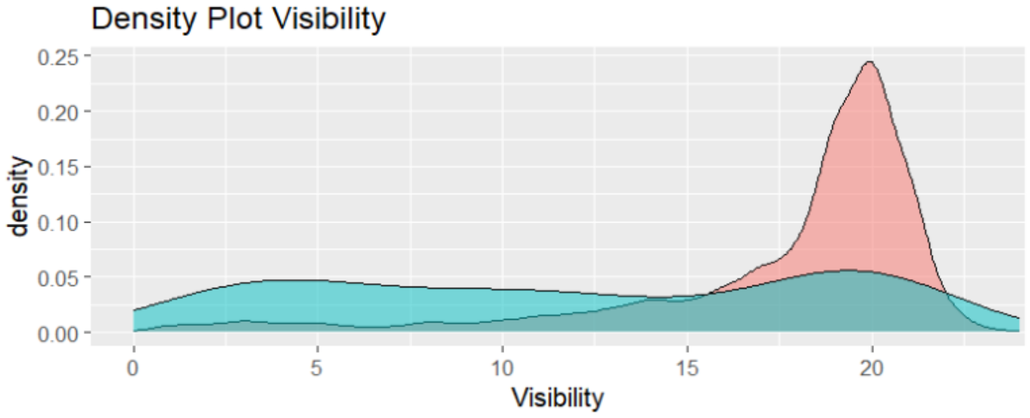


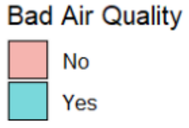
BIVARIATE DENSITY ANALYSIS

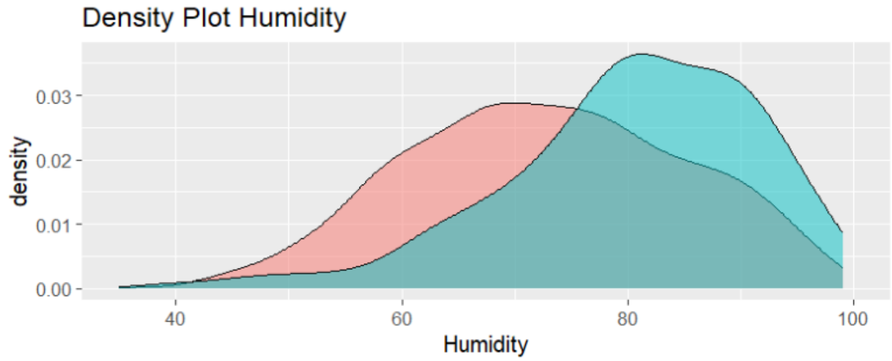
CONTINUOUS FEATURES

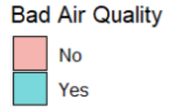


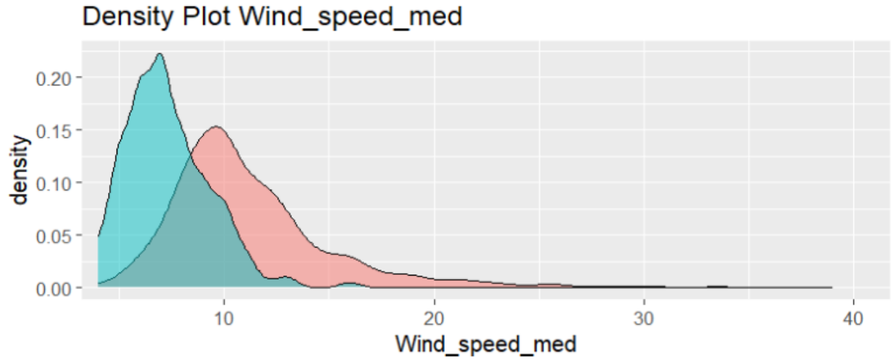


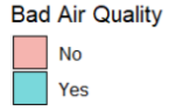


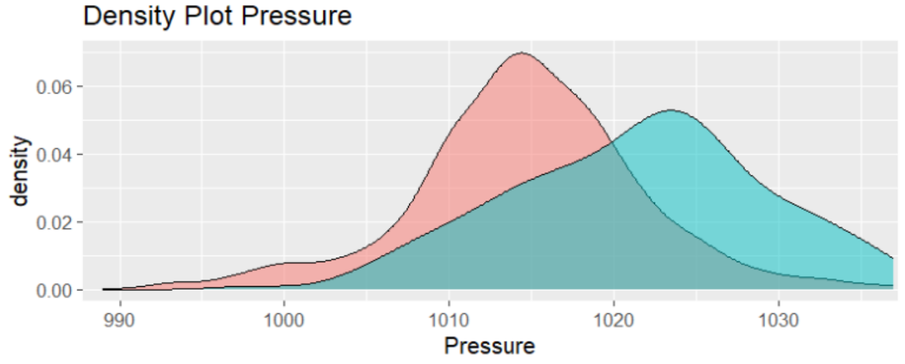


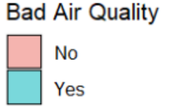




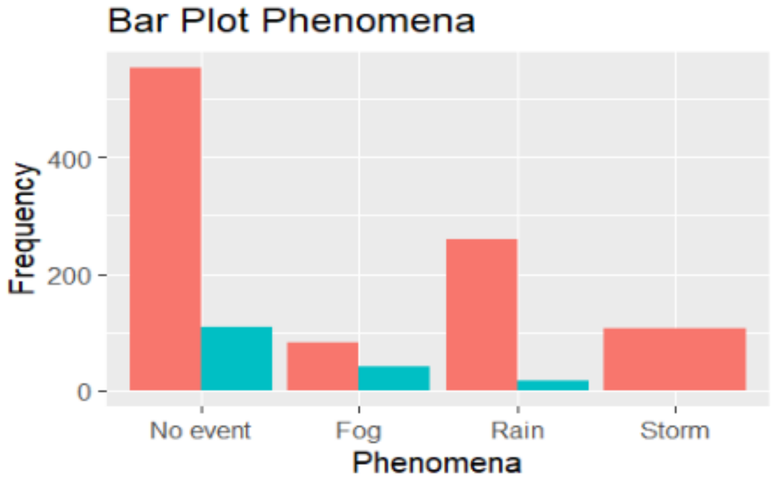


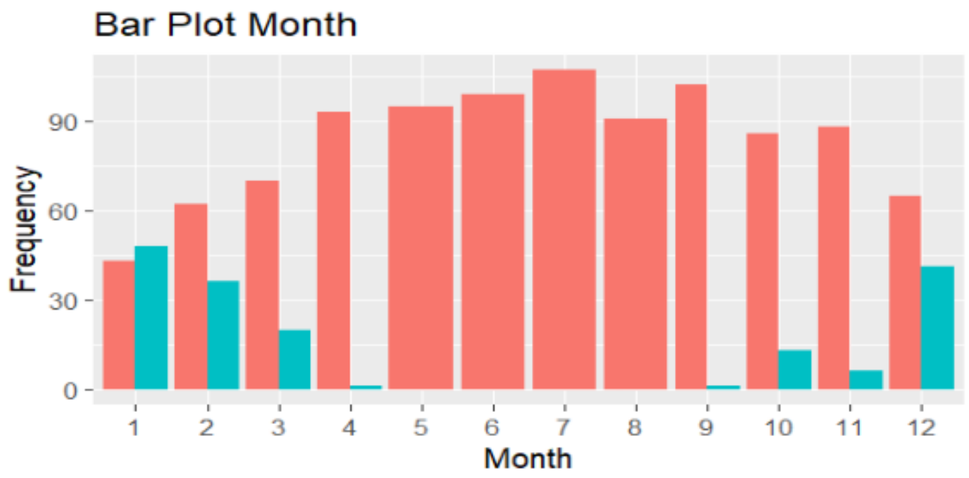


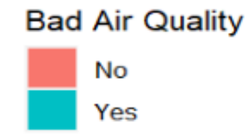


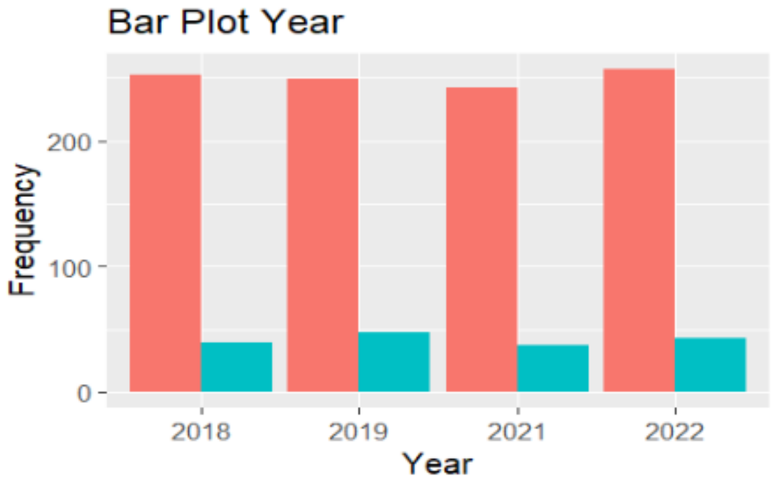


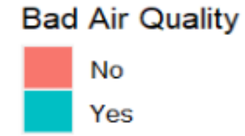
BIVARIATE CATEGORICAL ANALYSIS

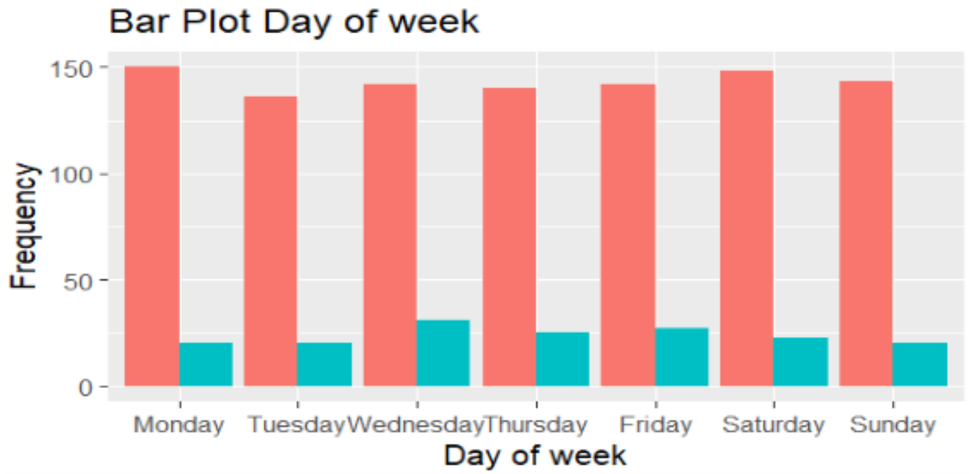


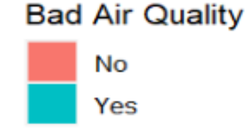












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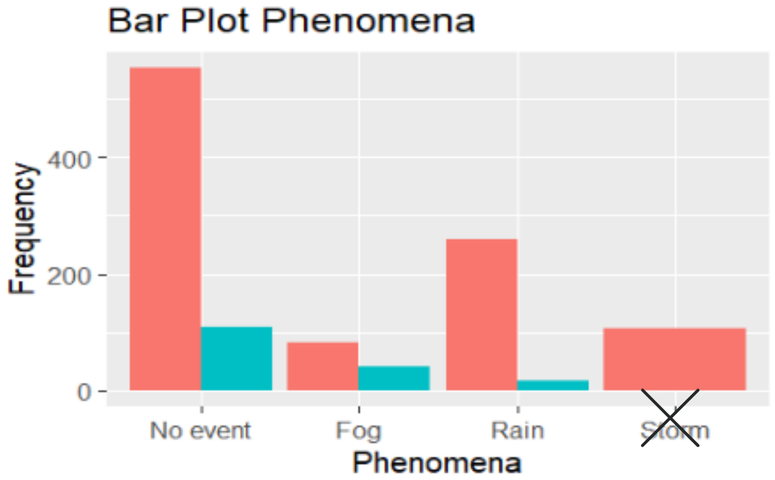
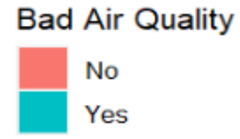
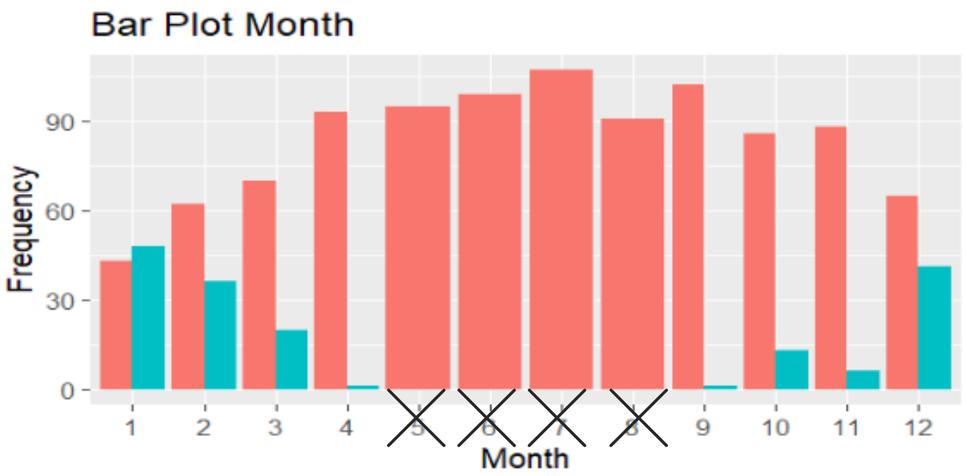
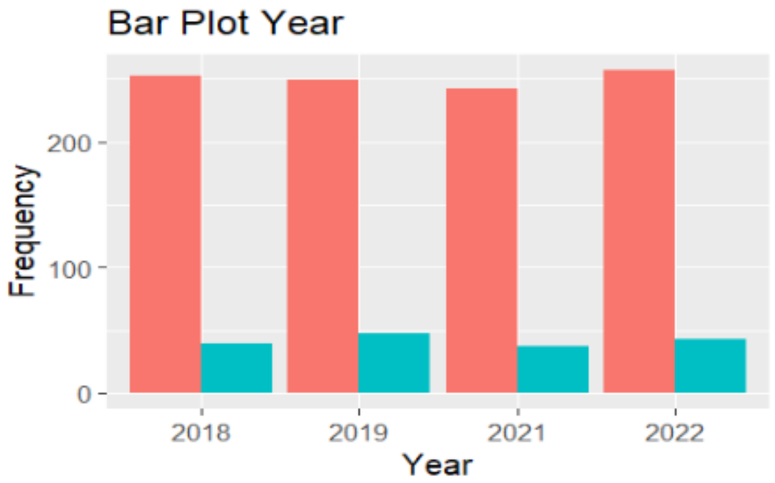
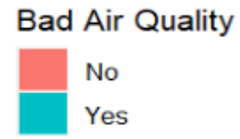
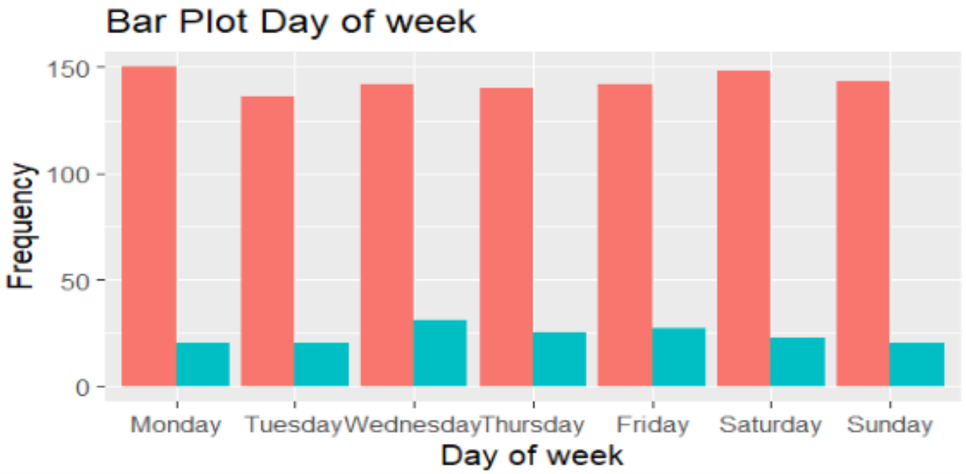


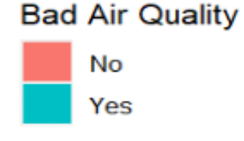












FINAL DATASET AND UNDERSAMPLING

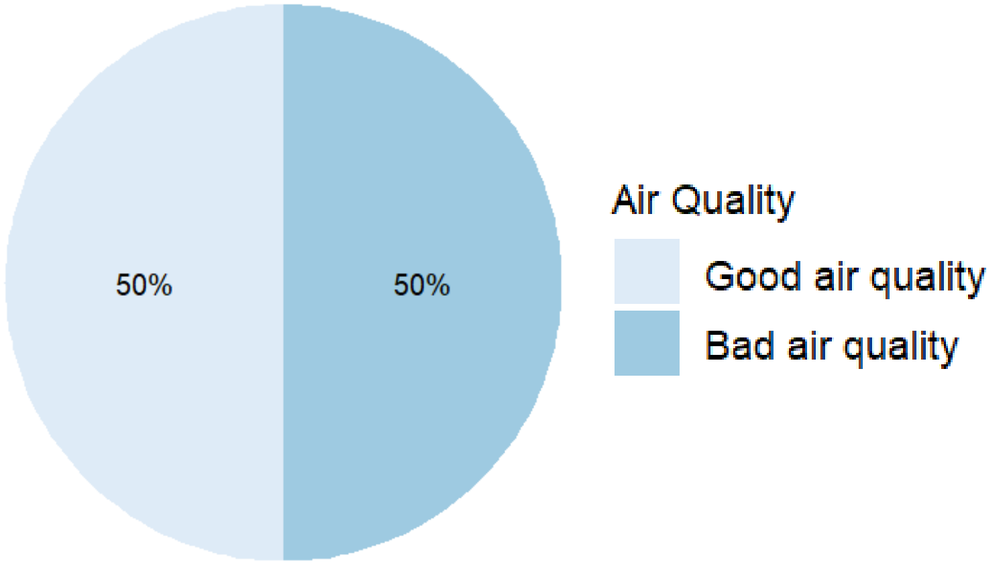
The **final training dataset** is composed of 743 occurrences and 10 features

9 PREDICTORS

CONTINUOUS	CATEGORICAL
T_max	Year
Pressure	Month
Humidity	Day_of_week
Visibility	Phenomena
Wind_speed_med	

RESPONSE: BadAirQuality

To balance the classes, **undersampling** technique is applied. The balanced training set contains 332 obervations



MODELS

METRICS

- **Accuracy**, used to measure the overall correctness of the model
- **Precision**
- **Sensitivity**. This metrics shows the extent to which the model is able to detect the days with high PM10 values
- **F1-Score,** harmonic mean of Precision and Sensitivity

Logistic Regression on the original dataset

- All the predictors are initially included
- Since the dataset contains categorical predictors, the presence of multicollinearity is checked by the means of Generalized Variance Inflaction Factor (GVIF)

	GVIF	Df	GVIF^(1/(2*Df))
T_max	3.290769	1	1.814048
Humidity	3.579425	1	1.891937
Visibility	3.266605	1	1.807375
Wind_speed_med	1.555637	1	1.247252
Pressure	1.472572	1	1.213496
Phenomena	2.623416	2	1.272673
Year	1.364436	3	1.053155
Month	5.168010	7	1.124480
Day_of_week	1.200242	6	1.015327

Logistic Regression: original dataset

		TRUE	
		0	1
PRED	0	137	17
	1	11	23

- Variable selection: Backward Spewise selection based on the Bayesian Information Criterion (BIC)
- Initial threshold: 0.5

```
Coefficients:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)    -41.93796   15.88063  -2.641 0.008270 **
T_max           -0.21235    0.02662  -7.977 1.50e-15 ***
Visibility      -0.13698    0.02598  -5.273 1.34e-07 ***
Wind_speed_med  -0.36897    0.05822  -6.337 2.34e-10 ***
Pressure         0.04662    0.01551   3.005 0.002654 **
PhenomenaFog    -1.43224    0.38665  -3.704 0.000212 ***
PhenomenaRain   -1.66530    0.44178  -3.770 0.000164 ***
```

ACCURACY	PRECISION	SENSITIVITY	F1-SCORE
0.851	0.676	0.575	0.622

Logistic Regression: undersampled dataset

		TRUE	
		0	1
PRED	0	130	8
	1	18	32

- The results obtained in terms of Recall on the original dataset are poor
- Fitting the model on the undersampled dataset with Backward Stepwise Selection successfully decreases the rate of FN
- Optimizating the threshold

	0.4	0.5	0.6
ACCURACY	0.809	0.824	0.862
PRECISION	0.530	0.559	0.640
SENSITIVITY	0.875	0.825	0.800
F1-SCORE	0.660	0.667	0.711

Logistic Regression with interactions: undersampled dataset

ACCURACY	0.819
PRECISION	0.545
SENSITIVITY	0.900
F1-SCORE	0.679

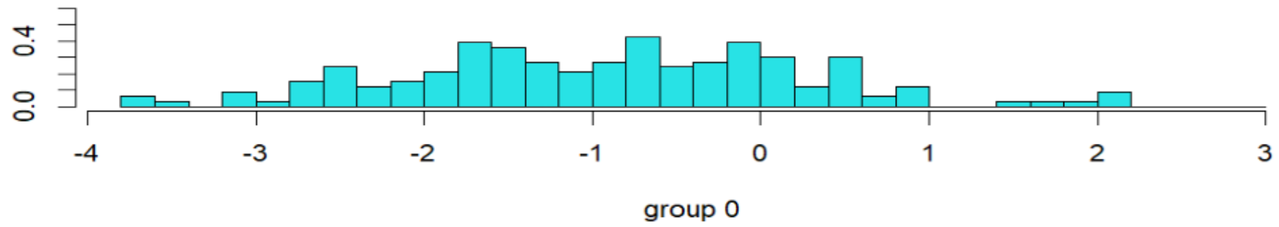
- Main effects: features selected by the Backward Stepwise procedure
- Interaction effects: interactions between the numerical variables kept
- After fitting the model, Backward Stepwise selection is again performed with AIC
- **Best threshold:** 0.4

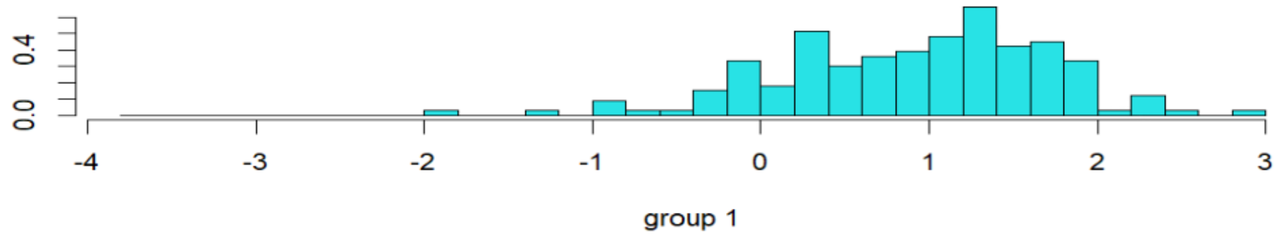
```
Coefficients:
                                 Estimate Std. Error z value Pr(>|z|)
(Intercept)                    236.852331 176.762778   1.340  0.18026
Visibility                     -25.793239  11.344209  -2.274  0.02298 *
Pressure                        -0.228198   0.173591  -1.315  0.18865
Wind_speed_med                 -27.334825  21.607728  -1.265  0.20585
T_max                           -9.369122   6.136833  -1.527  0.12683
PhenomenaFog                    -1.352649   0.525970  -2.572  0.01012 *
PhenomenaRain                   -1.559590   0.563537  -2.768  0.00565 **
Visibility:Pressure              0.025306   0.011144   2.271  0.02316 *
Visibility:Wind_speed_med        2.482656   1.307560   1.899  0.05760 .
Pressure:Wind_speed_med          0.026679   0.021275   1.254  0.20984
Visibility:T_max                -0.016235   0.006100  -2.661  0.00778 **
Pressure:T_max                   0.009204   0.006030   1.526  0.12696
Visibility:Pressure:Wind_speed_med -0.002447   0.001287  -1.901  0.05729 .
```

Linear Discriminant Analysis (LDA)

ACCURACY	0.830
PRECISION	0.565
SENSITIVITY	0.875
F1-SCORE	0.686

- All the following models are fitted on the undersampled dataset and on the features selected by the backward stepwise procedure since the achieved performance are better
- Normality assumptions do not hold
- **Best threshold**: 0.3





Quadratic Discriminant Analysis (QDA)

ACCURACY	0.835
PRECISION	0.576
SENSITIVITY	0.850
F1-SCORE	0.687

- Assumption: each class has its own covariance matrix (less restrictive than LDA)
- Quadratic decision boundary
- **Best threshold**: 0.5

		TRUE	
		0	**1**
PRED	**0**	123	6
	1	25	34

Naive Bayes

ACCURACY	0.835
PRECISION	0.576
SENSITIVITY	0.850
F1-SCORE	0.687

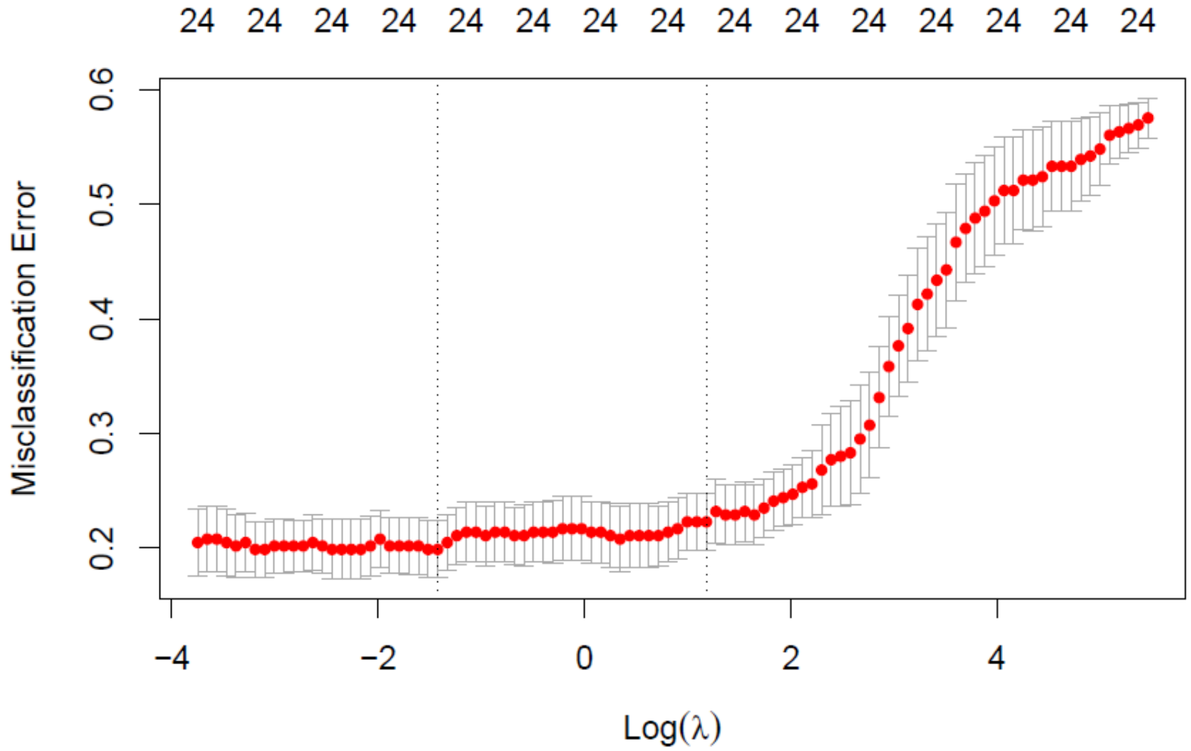
- Independence assumption of the covariates in each class fails
- For the quantitative variables, it's like applying QDA with the additionally assumption of independence
- For categorical variables, the distribution of each predictor in the specific class can be computed considering the specific proportions
- **Best threshold**: 0.5

		TRUE	
		0	**1**
PRED	**0**	123	6
	1	25	34

Ridge regression

ACCURACY	0.835
PRECISION	0.576
SENSITIVITY	0.850
F1-SCORE	0.687

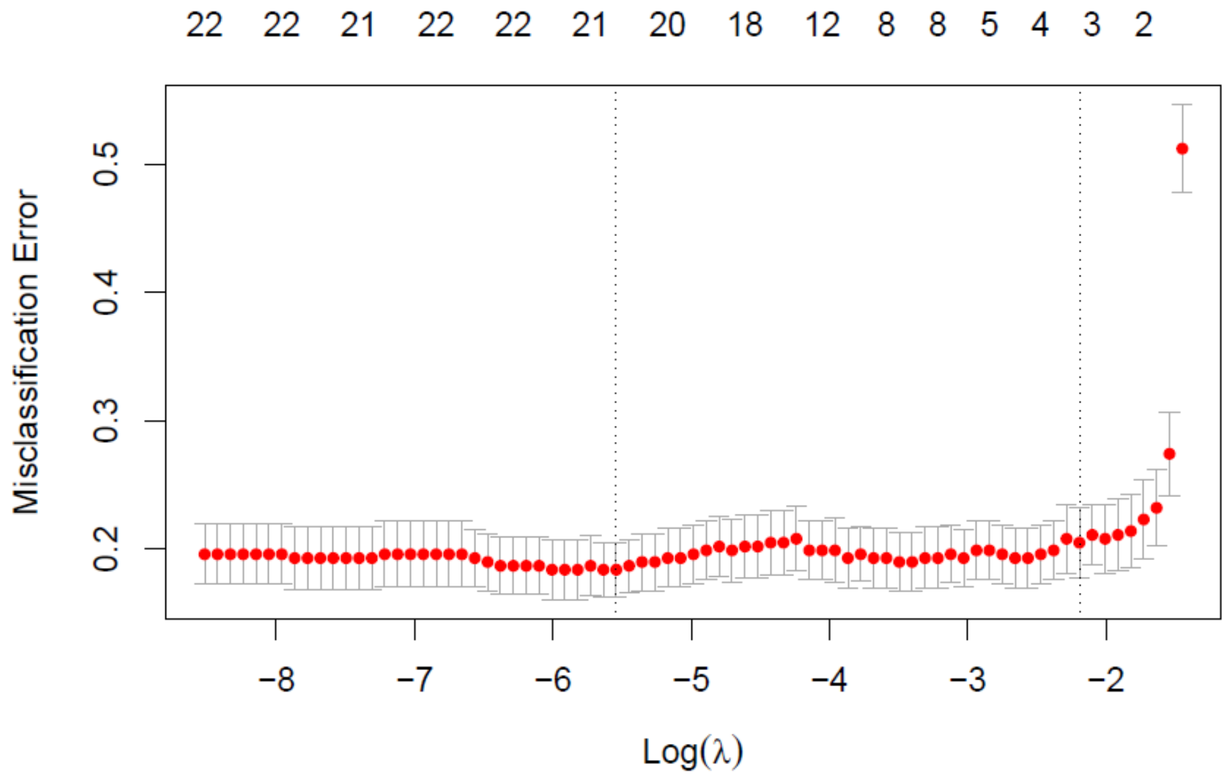
- All features are kept
- Shrinking of the coefficients towards 0
- L2 penalization
- **Best λ :** 0.241



Lasso regression

ACCURACY	0.814
PRECISION	0.541
SENSITIVITY	0.825
F1-SCORE	0.653

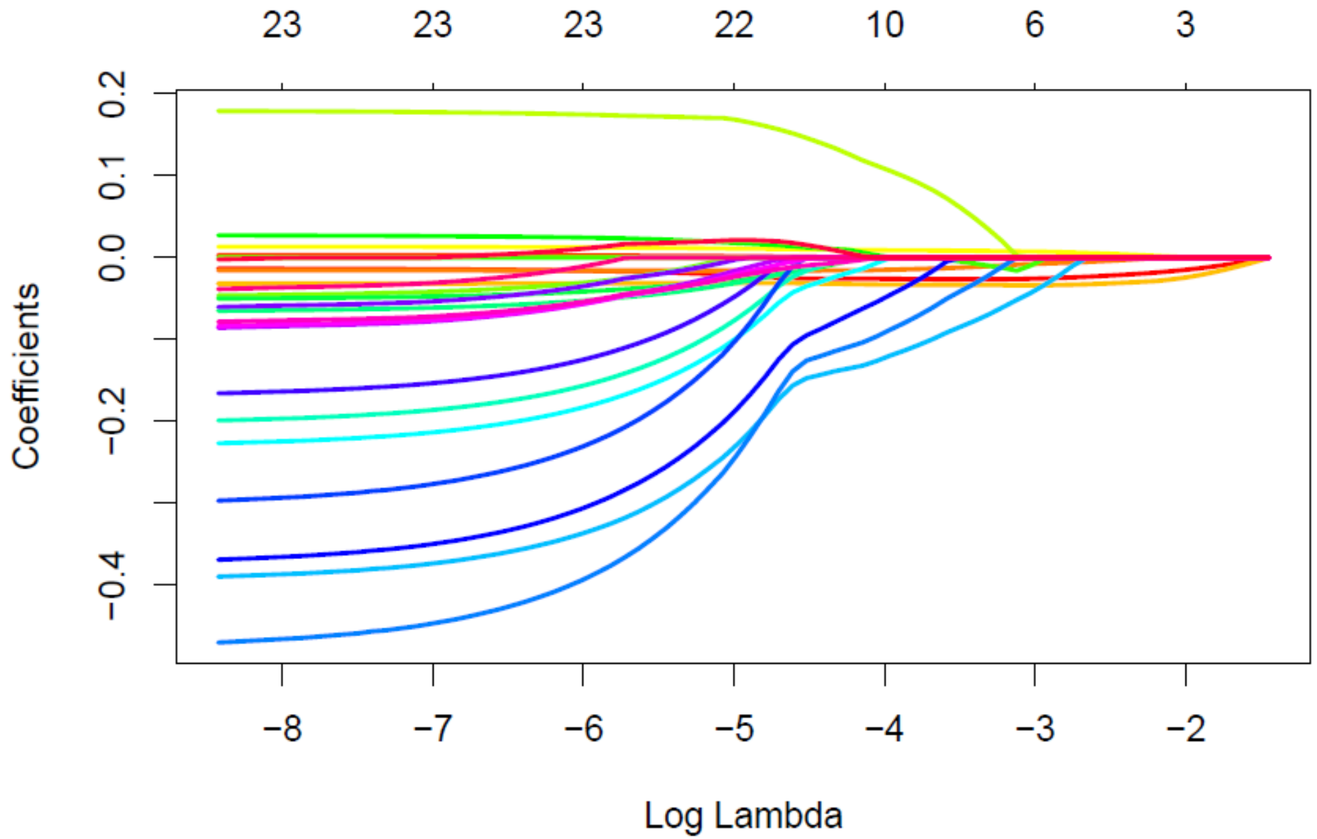
- It perform feature selection: non significant features are set exactly equal to 0
- L1 penalization
- **Best λ :** 0.004



Lasso regression

- T_max
- Humidity
- Visibility
- Wind_speed_med
- Pressure
- PhenomenaNo event
- PhenomenaFog
- PhenomenaRain
- Year19
- Year21
- Year22
- Month2
- Month3
- Month4
- Month9
- Month10
- Month11
- Month12
- Day_of_weekMonday
- Day_of_weekSaturday
- Day_of_weekSunday
- Day_of_weekThursday
- Day_of_weekTuesday
- Day_of_weekWednesday

The most significant predictors are similar to the one kept by the backward stepwise process:
T_max, Visibility, Wind_speed_med, Pressure, PhenomenaRain, Month4



K-Nearest Neighbors (KNN)

ACCURACY	0.771
PRECISION	0.478
SENSITIVITY	0.800
F1-SCORE	0.598

- Non-parametric model
- Since the dataset contain numerical and categorical features, traditional distance metrics are not suitable.
- Solution: **Gower distance**

$$\text{Gower}(X, Y) = \frac{\sum_{i=1}^{n} w_i \cdot d(x_i, y_i)}{\sum_{i=1}^{n} w_i}$$

- For numeric variables, Gower distance uses a normalized L1-norm
- For categorical covariates, it uses a simple matching coefficient (0/1): same level implies 0 distance, 1 otherwise
- **Number of neighbors K** = 5

MODEL COMPARISON

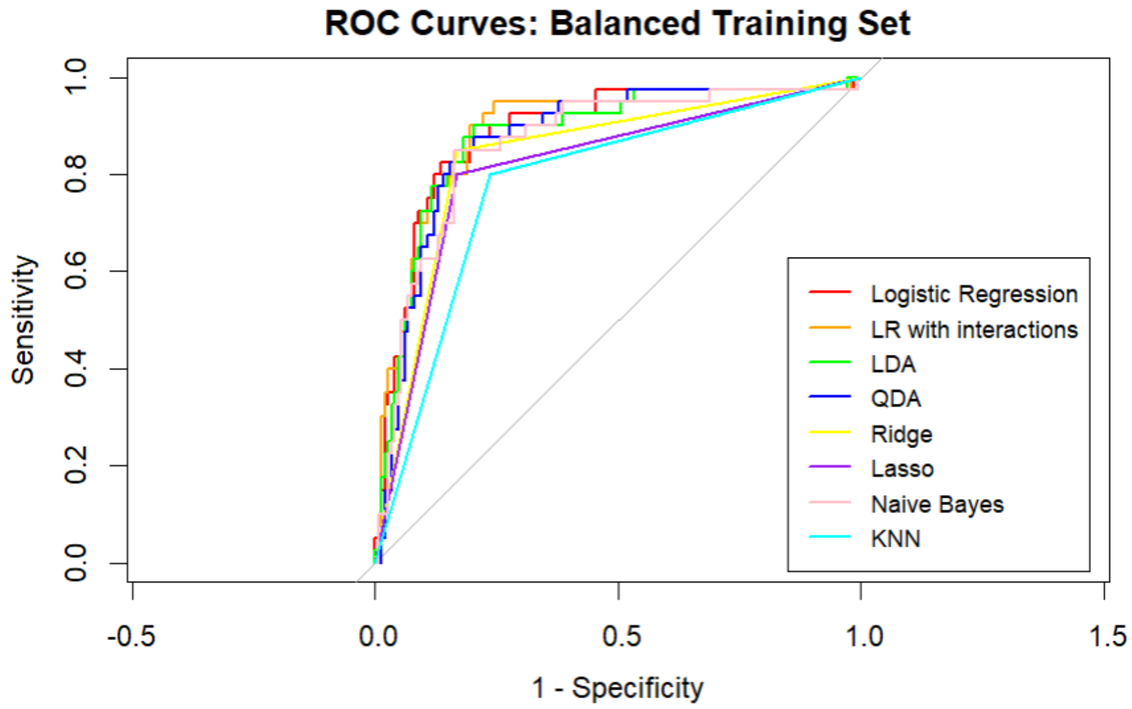
UNDERSAMPLED DATASET

- All the models have good performances, with the exception of KNN whose accuracy is slightly lower

- Best overall model:
  - Logistic Regression with 0.6 as threshold

- Models with highest Sensitivity and AUC:
  - Logistic Regression with interactions
  - LDA

Model	Accuracy	Recall	Precision	F1_score	AUC
Logistic Regression	0.862	0.800	0.640	0.711	0.888
Logistic with interactions	0.819	0.900	0.545	0.679	0.892
LDA	0.830	0.875	0.565	0.686	0.879
QDA	0.835	0.850	0.576	0.687	0.872
Ridge	0.835	0.850	0.576	0.687	0.841
Lasso	0.824	0.800	0.561	0.660	0.816
Naive Bayes	0.835	0.850	0.576	0.687	0.864
KNN	0.771	0.800	0.478	0.598	0.782



CONCLUSIONS

INTERPRETABILITY GOALS

Meteorological conditions can accurately predict whether the PM10 particulate levels in the air will be high or low in the following day

The best predictors are:

- **Phenomena:** the presence of rain and fog tends to lower the likelihood of high PM10

- **Visibility, T_max** and **Wind_speed_med**. High values exhibit a negative influence on this probability.

- **Pressure**. High pressure systems increases the probability.