

Script R - Parte 2 - Thiago Menezes (ajuste para estilo do python)

1) Importação do conjunto de dados "dataset_st" no RStudio.

2) Conversão dos dados para em um objeto tsibble:

```
install.packages("dplyr")
install.packages("tsibble")
install.packages("fabletools")
install.packages("ggplot2")

library(dplyr)
library(tsibble)
library(fabletools)
library(ggplot2)

dataset_st <- dataset_st |>
  mutate(mes = yearmonth(mes)) |>
  as_tsibble(index = mes)

dataset_st
```

3) Geração das séries temporais por grupos:

```
library(dplyr)
library(tidyr)
library(ggplot2)

# Paleta "tab10" do Matplotlib
tab10 <- c(
  "#1f77b4", "#ff7f0e", "#2ca02c", "#d62728",
  "#9467bd", "#8c564b", "#e377c2", "#7f7f7f",
  "#bcbd22", "#17becf"
)

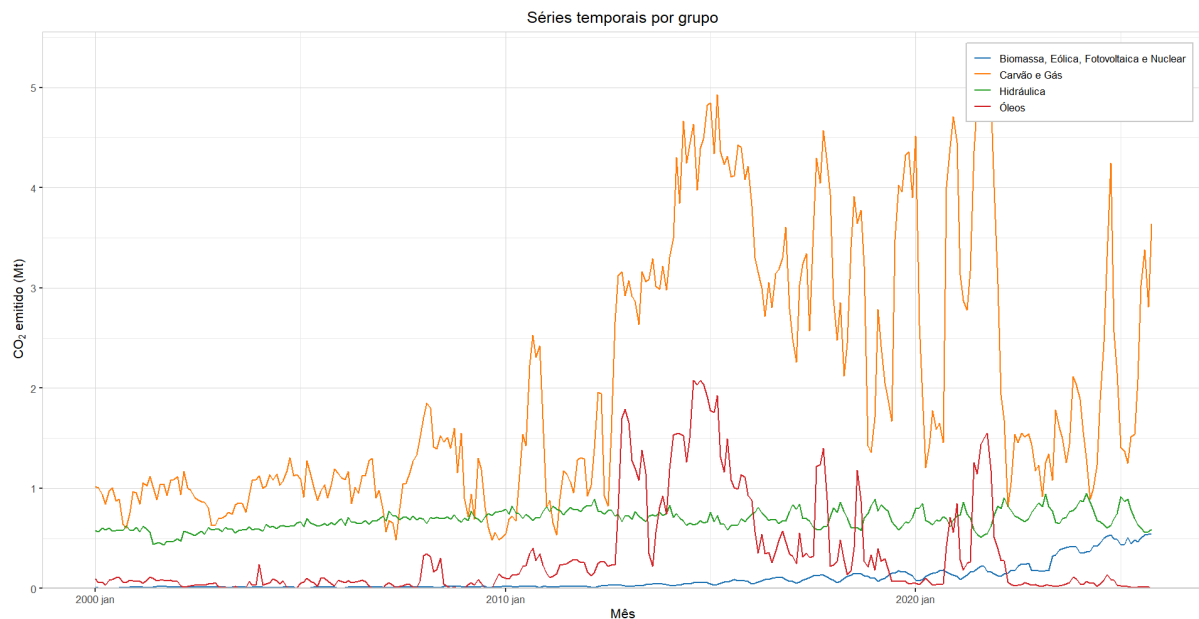
theme_python <- function(base_size = 14) {
  theme_bw(base_size = base_size) +
    theme(
      panel.background = element_rect(fill = "white"),
      panel.grid.major = element_line(colour = "grey85", linewidth = 0.4),
      panel.grid.minor = element_line(colour = "grey92", linewidth = 0.2),
      panel.border = element_rect(colour = "grey80", fill = NA),
      plot.title = element_text(hjust = 0.5),
      legend.title = element_blank()
    )
}
```

```

# Tema global
theme_set(theme_python())

dataset_st %>%
  select(mes, grupo_befn, grupo_cg, grupo_hidraulica, grupo_o) %>%
  pivot_longer(-mes, names_to = "grupo", values_to = "valor") %>%
  mutate(
    grupo = recode(
      grupo,
      grupo_befn = "Biomassa, Eólica, Fotovoltaica e Nuclear",
      grupo_cg = "Carvão e Gás",
      grupo_hidraulica = "Hidráulica",
      grupo_o = "Óleos"
    )
  ) %>%
  ggplot(aes(x = mes, y = valor, colour = grupo)) +
  geom_line(linewidth = 0.9) +
  scale_colour_manual(values = tab10[1:4]) +
  labs(
    y = expression("CO"[2] * " emitido (Mt)"),
    x = "Mês",
    title = "Séries temporais por grupo"
  ) +
  scale_y_continuous(expand = expansion(mult = c(0, 0.02))) +
  theme(
    legend.position = c(0.99, 0.98), # dentro do gráfico, canto sup. dir.
    legend.justification = c(1, 1),
    legend.background = element_rect(fill = "white", colour = "grey80"),
    legend.key.width = unit(1.5, "lines")
  )

```



4) Séries temporais por grupos cortadas:

```
library(dplyr)
library(tidyr)
library(ggplot2)
library(lubridate)
library(tsibble)
```

```
# --- manter apenas TREINO (até 2023 Dez) ---
train_only <- dataset_st %>%
  filter(mes <= yearmonth("2023 Dec"))
```

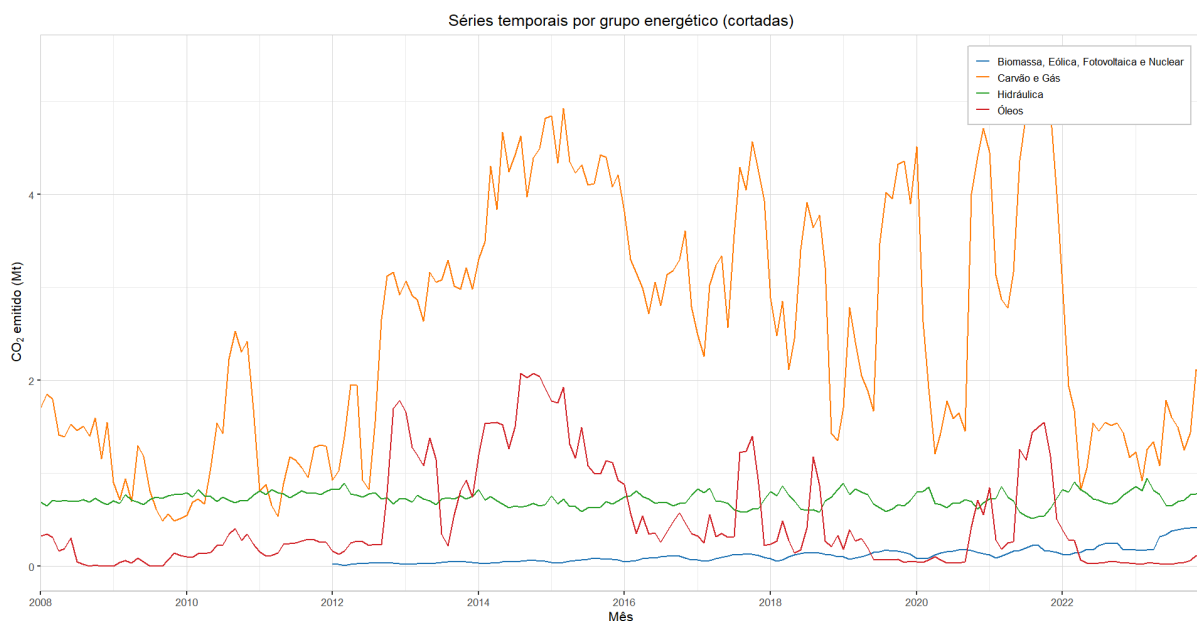
```
# --- aplicar cortes ANTES de plotar ---
train_only_cut <- train_only %>%
  mutate(
    grupo_befn = if_else(mes < yearmonth("2012 Jan"), NA_real_, grupo_befn),
    grupo_cg = if_else(mes < yearmonth("2008 Jan"), NA_real_, grupo_cg),
    grupo_hidraulica = if_else(mes < yearmonth("2008 Jan"), NA_real_, grupo_hidraulica),
    grupo_o = if_else(mes < yearmonth("2008 Jan"), NA_real_, grupo_o)
  )
```

```
# --- GRÁFICO (somente treinamento, séries cortadas) ---
train_only_cut %>%
  filter(mes >= yearmonth("2005 Jan")) %>% # começa no ano desejado
  select(mes, grupo_befn, grupo_cg, grupo_hidraulica, grupo_o) %>%
  pivot_longer(-mes, names_to = "grupo", values_to = "valor") %>%
  mutate(
    grupo = recode(
      grupo,
      grupo_befn = "Biomassa, Eólica, Fotovoltaica e Nuclear",
```

```

    grupo_cg      = "Carvão e Gás",
    grupo_hidraulica = "Hidráulica",
    grupo_o       = "Óleos"
  ),
  date = as.Date(mes)
) %>%
ggplot(aes(x = date, y = valor, colour = grupo)) +
  geom_line(linewidth = 0.9, na.rm = TRUE) +
  scale_colour_manual(values = tab10[1:4]) +
  labs(
    title = "Séries temporais por grupo energético (cortadas)",
    x = "Mês",
    y = expression("CO"[2] * " emitido (Mt)")
  ) +
  scale_x_date(
    limits = c(as.Date(yearmonth("2008 Jan")), max(as.Date(train_only_cut$mes))),
    expand = c(0, 0),
    date_breaks = "2 years",
    date_labels = "%Y"
  ) +
  theme(
    legend.position = c(0.99, 0.98), # canto superior direito, dentro
    legend.justification = c(1, 1),
    legend.background = element_rect(fill = "white", colour = "grey80"),
    legend.title = element_blank()
  )
)

```



5) Divisão dos dados em treinamento e teste:

```

# --- Treino: 2008–2023 ---
hidraulica_treino_2008_2023 <- dataset_st |>
  select(mes, grupo_hidraulica) |>
  filter_index("2008 Jan" ~ "2023 Dec")

# --- Teste: 2024–2025 ---
hidraulica_teste_2024_25 <- dataset_st |>
  select(mes, grupo_hidraulica) |>
  filter_index("2024 Jan" ~ "2025 Oct")

oleos_treino_2008_2023 <- dataset_st |>
  select(mes, grupo_o) |>
  filter_index("2008 Jan" ~ "2023 Dec")

oleos_teste_2024_25 <- dataset_st |>
  select(mes, grupo_o) |>
  filter_index("2024 Jan" ~ "2025 Oct")

cg_treino_2008_2023 <- dataset_st |>
  select(mes, grupo_cg) |>
  filter_index("2008 Jan" ~ "2023 Dec")

cg_teste_2024_25 <- dataset_st |>
  select(mes, grupo_cg) |>
  filter_index("2024 Jan" ~ "2025 Oct")

befn_treino_2012_2023 <- dataset_st |>
  select(mes, grupo_befn) |>
  filter_index("2012 Jan" ~ "2023 Dec")

befn_teste_2024_25 <- dataset_st |>
  select(mes, grupo_befn) |>
  filter_index("2024 Jan" ~ "2025 Oct")

```

6) Transformações Box-cox:

```

library(ggplot2)
library(fabletools)
library(feasts)
library(latex2exp)
library(patchwork)

# -----
# Hidráulica
# -----
lambda_hid <- hidraulica_treino_2008_2023 |>

```

```
features(grupo_hidraulica, features = guerrero) |>
pull(lambda_guerrero)
```

```
p_hid <- hidraulica_treino_2008_2023 |>
autoplot(box_cox(grupo_hidraulica, lambda_hid)) +
labs(y = "",
      title = latex2exp::TeX(paste0(
        "Hidráulica —  $\lambda =$ ", round(lambda_hid,2)))) +
theme_minimal(14)
```

```
# -----
# Óleos
# -----
```

```
lambda_ole <- oleos_treino_2008_2023 |>
features(grupo_o, features = guerrero) |>
pull(lambda_guerrero)
```

```
p_ole <- oleos_treino_2008_2023 |>
autoplot(box_cox(grupo_o, lambda_ole)) +
labs(y = "",
      title = latex2exp::TeX(paste0(
        "Óleos —  $\lambda =$ ", round(lambda_ole,2)))) +
theme_minimal(14)
```

```
# -----
# Carvão & Gás
# -----
```

```
lambda_cg <- cg_treino_2008_2023 |>
features(grupo_cg, features = guerrero) |>
pull(lambda_guerrero)
```

```
p_cg <- cg_treino_2008_2023 |>
autoplot(box_cox(grupo_cg, lambda_cg)) +
labs(y = "",
      title = latex2exp::TeX(paste0(
        "Carvão e Gás —  $\lambda =$ ", round(lambda_cg,2)))) +
theme_minimal(14)
```

```
# -----
# Renováveis (BEFN)
# -----
```

```
lambda_befn <- befn_treino_2012_2023 |>
features(grupo_befn, features = guerrero) |>
pull(lambda_guerrero)
```

```
p_befn <- befn_treino_2012_2023 |>
  autoplot(box_cox(grupo_befn, lambda_befn)) +
  labs(y = "",
       title = latex2exp::TeX(paste0(
         "Biomassa, Eólica, Fotovoltaica e Nuclear —  $\lambda = ", round(lambda_befn,2))))
  +
  theme_minimal(14)$ 
```

```
# -----
# 2 x 2
# -----
```

```
(p_hid | p_ole) /
(p_cg | p_befn)
```

```
p_hid <- hidraulica_treino_2008_2023 |>
  autoplot(box_cox(grupo_hidraulica, lambda_hid)) +
  scale_colour_manual(values = tab10[1]) +
  labs(
    y = "",
    title = latex2exp::TeX(
      paste0("Hidráulica —  $\lambda = ", round(lambda_hid,2))
    )
  ) +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.position = "none"
  )$ 
```

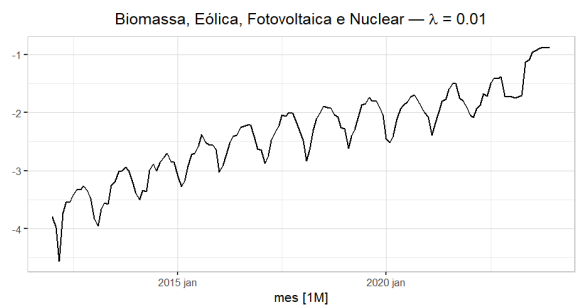
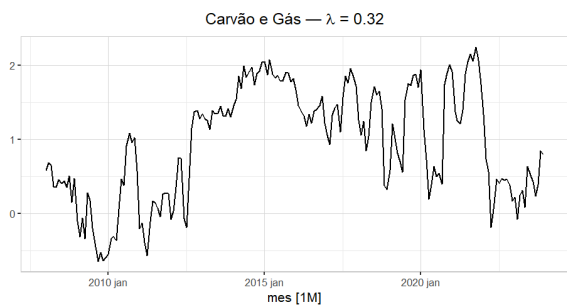
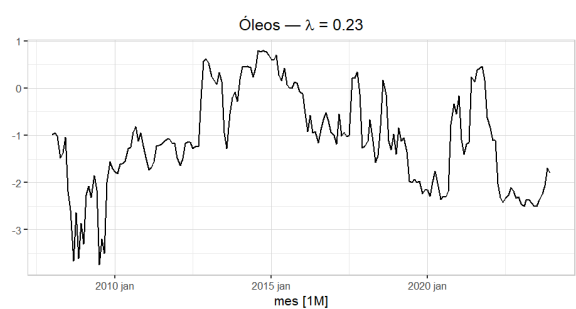
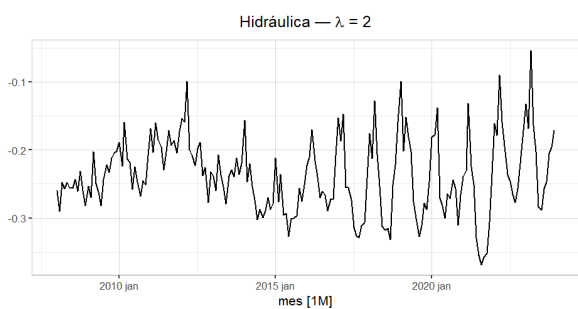
```
p_ole <- oleos_treino_2008_2023 |>
  autoplot(box_cox(grupo_o, lambda_ole)) +
  scale_colour_manual(values = tab10[2]) +
  labs(
    y = "",
    title = latex2exp::TeX(
      paste0("Óleos —  $\lambda = ", round(lambda_ole,2))
    )
  ) +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.position = "none"
  )$ 
```

```
p_cg <- cg_treino_2008_2023 |>
  autoplot(box_cox(grupo_cg, lambda_cg)) +
  scale_colour_manual(values = tab10[3]) +
```

```
labs(
  y = "",
  title = latex2exp::TeX(
    paste0("Carvão e Gás —  $\lambda =$ ", round(lambda_cg,2))
  )
) +
theme(
  plot.title = element_text(hjust = 0.5),
  legend.position = "none"
)
```

```
p_befn <- befn_treino_2012_2023 |>
autoplot(box_cox(grupo_befn, lambda_befn)) +
scale_colour_manual(values = tab10[4]) +
labs(
  y = "",
  title = latex2exp::TeX(
    paste0("Biomassa, Eólica, Fotovoltaica e Nuclear —  $\lambda =$ ",
round(lambda_befn,2))
  )
) +
theme(
  plot.title = element_text(hjust = 0.5),
  legend.position = "none"
)
```

```
(p_hid | p_ole) /
(p_cg | p_befn)
```



7) Ajuste dos modelos ARIMA (automático) para cada grupo:

HIDRÁULICA

```
hidraulica_bc <- hidraulica_treino_2008_2023 %>%  
  mutate(co2_bc = box_cox(grupo_hidraulica, lambda_hid))
```

ÓLEOS

```
oleos_bc <- oleos_treino_2008_2023 %>%  
  mutate(co2_bc = box_cox(grupo_o, lambda_ole))
```

CARVÃO & GÁS

```
cg_bc <- cg_treino_2008_2023 %>%  
  mutate(co2_bc = box_cox(grupo_cg, lambda_cg))
```

BEFN (Renováveis)

```
befn_bc <- befn_treino_2012_2023 %>%  
  mutate(co2_bc = box_cox(grupo_befn, lambda_befn))
```

```
library(fable)
```

```
library(fabletools)
```

HIDRÁULICA

```
fit_hid_arima <- hidraulica_bc %>%  
  model(  
    arima = ARIMA(co2_bc, stepwise = FALSE, approx = FALSE)  
  )
```

ÓLEOS

```
fit_ole_arima <- oleos_bc %>%  
  model(  
    arima = ARIMA(co2_bc, stepwise = FALSE, approx = FALSE)  
  )
```

CARVÃO & GÁS

```
fit_cg_arima <- cg_bc %>%  
  model(  
    arima = ARIMA(co2_bc, stepwise = FALSE, approx = FALSE)  
  )
```

RENOVÁVEIS + NUCLEAR (BEFN)

```
fit_befn_arima <- befn_bc %>%  
  model(  
    arima = ARIMA(co2_bc, stepwise = FALSE, approx = FALSE)  
  )
```

```
report(fit_hid_arima)
report(fit_ole_arima)
report(fit_cg_arima)
report(fit_befn_arima)
```

```
> report(fit_hid_arima)
```

```
Series: co2_bc
```

```
Model: ARIMA(2,0,0) (2,1,1) [12]
```

```
Coefficients:
```

	ar1	ar2	sar1	sar2	sma1
	0.9866	-0.1879	-0.0819	-0.2388	-0.6082
s.e.	0.0747	0.0762	0.1134	0.0902	0.1018

```
sigma^2 estimated as 0.0005725: log likelihood=413.37
```

```
AIC=-814.73 AICc=-814.25 BIC=-795.58
```

```
> report(fit_ole_arima)
```

```
Series: co2_bc
```

```
Model: ARIMA(0,1,4) (2,0,0) [12]
```

```
Coefficients:
```

	ma1	ma2	ma3	ma4	sar1	sar2
	-0.021	0.0503	-0.2379	-0.1198	0.0836	-0.1573
s.e.	0.073	0.0711	0.0828	0.0756	0.0788	0.0831

```
sigma^2 estimated as 0.1702: log likelihood=-99.3
```

```
AIC=212.6 AICc=213.21 BIC=235.36
```

```
> report(fit_cg_arima)
```

```
Series: co2_bc
```

```
Model: ARIMA(0,1,4) (2,0,0) [12]
```

```
Coefficients:
```

	ma1	ma2	ma3	ma4	sar1	sar2
	0.0971	-0.0947	-0.1529	-0.3150	0.0457	0.1613
s.e.	0.0710	0.0717	0.0759	0.0827	0.0723	0.0759

```
sigma^2 estimated as 0.08146: log likelihood=-29.07
```

```
AIC=72.15 AICc=72.76 BIC=94.91
```

```
> report(fit_befn_arima)
```

```
Series: co2_bc
```

```
Model: ARIMA(3,0,1) (0,1,1) [12] w/ drift
```

```
Coefficients:
```

	ar1	ar2	ar3	ma1	sma1	constant
	0.8309	-0.1311	0.2660	-0.4601	-0.8708	0.0077
s.e.	0.1913	0.1307	0.1322	0.1838	0.1624	0.0011

```
sigma^2 estimated as 0.01429: log likelihood=88
```

```
AIC=-162 AICc=-161.1 BIC=-141.82
```

8) Ajuste do e ETS com Box-Cox para cada grupo:

```
library(fable)
```

```
# HIDRÁULICA
```

```
fit_hid_ets <- hidraulica_bc %>%  
  model(  
    ets = ETS(co2_bc)  
  )
```

```
# ÓLEOS
```

```
fit_ole_ets <- oleos_bc %>%  
  model(  
    ets = ETS(co2_bc)  
  )
```

```
# CARVÃO & GÁS
```

```
fit_cg_ets <- cg_bc %>%  
  model(  
    ets = ETS(co2_bc)  
  )
```

```
# BEFN
```

```
fit_befn_ets <- befn_bc %>%  
  model(  
    ets = ETS(co2_bc)  
  )
```

```
fit_hid_ets
```

```
fit_ole_ets
```

```
fit_cg_ets
```

```
fit_befn_ets
```

```
report(fit_hid_ets)
```

```
report(fit_ole_ets)
```

```
report(fit_cg_ets)
```

```
report(fit_befn_ets)
```

```
> report(fit_hid_ets)
```

```
Series: co2_bc
```

```
Model: ETS(A,N,A)
```

```
Smoothing parameters:
```

```
alpha = 0.8386846
```

```
gamma = 0.1578135
```

```
Initial states:
```

```
      l[0]      s[0]      s[-1]      s[-2]      s[-3]      s[-4]  
s[-5]      s[-6]      s[-7]
```

```

-0.3380537 0.04870997 0.01194264 0.001345753 -0.03386021 -0.007175918
-0.03963994 -0.07013598 -0.02834456
      s[-8]      s[-9]      s[-10]      s[-11]
-0.009038573 0.05204129 0.007170066 0.06698545

```

```
sigma^2: 8e-04
```

```

      AIC      AICc      BIC
-348.3707 -345.6434 -299.5082

```

```
> report(fit_ole_ets)
```

```
Series: co2_bc
```

```
Model: ETS(A,N,N)
```

```
Smoothing parameters:
```

```
alpha = 0.9906681
```

```
Initial states:
```

```
l[0]
```

```
-0.9838421
```

```
sigma^2: 0.1844
```

```

      AIC      AICc      BIC
688.7740 688.9016 698.5464

```

```
> report(fit_cg_ets)
```

```
Series: co2_bc
```

```
Model: ETS(A,N,N)
```

```
Smoothing parameters:
```

```
alpha = 0.9998999
```

```
Initial states:
```

```
l[0]
```

```
0.581717
```

```
sigma^2: 0.0898
```

```

      AIC      AICc      BIC
550.7614 550.8891 560.5339

```

```
> report(fit_befn_ets)
```

```
Series: co2_bc
```

```
Model: ETS(A,A,A)
```

```
Smoothing parameters:
```

```
alpha = 0.276589
```

```
beta = 0.03029959
```

```
gamma = 0.0001002197
```

```
Initial states:
```

```
l[0]
```

```
b[0]
```

```
s[0]
```

```
s[-1]
```

```
s[-2]
```

```
s[-3]
```

```
s[-4]
```

```
s[-5]      s[-6]      s[-7]
```

```

-3.683144 0.02525095 -0.05123652 0.08197678 0.2111572 0.2626876 0.282074
0.1891946 0.1274097 0.04237296

```

```
      s[-8]      s[-9]      s[-10]      s[-11]
```

```

-0.1369123 -0.3295867 -0.4228454 -0.256292

```

```

sigma^2: 0.0135

      AIC      AICc      BIC
113.0455 117.9027 163.5323

```

9) Ajuste dos modelos BENCHMARKS:

```

library(dplyr)
library(fable)
library(fabletools)
library(tsibble)

# =====
# Função correta para inversa Box-Cox
# =====
# Agora shift tem valor padrão = 0 → NÃO OCORRE MAIS O ERRO
inv_box_cox <- function(y_bc, lambda, shift = 0) {
  if (abs(lambda) < 1e-8) {
    exp(y_bc) - shift
  } else {
    (lambda * y_bc + 1)^(1 / lambda) - shift
  }
}

# =====
# Utilitária para aplicar inverse BC nas colunas previstas
# =====
inv_bc_across <- function(fc_tbl, lambda, cols = c(".mean", ".lower", ".upper")) {
  for (col in cols) {
    if (col %in% names(fc_tbl)) {
      fc_tbl[[col]] <- inv_box_cox(fc_tbl[[col]], lambda)
    }
  }
  fc_tbl
}

# =====
# HORIZONTES (número de períodos do teste)
# =====
h_hid <- nrow(hidraulica_teste_2024_25)
h_ole <- nrow(oleos_teste_2024_25)
h_cg <- nrow(cg_teste_2024_25)
h_befn <- nrow(befn_teste_2024_25)

# =====
# 1) Ajustar benchmarks (na série transformada co2_bc)
# =====

```

```
fit_hid_bench <- hidraulica_bc %>%
  model(
    naive = NAIVE(co2_bc),
    snaive = SNAIVE(co2_bc),
    mean = MEAN(co2_bc),
    drift = RW(co2_bc ~ drift())
  )
```

```
fit_ole_bench <- oleos_bc %>%
  model(
    naive = NAIVE(co2_bc),
    snaive = SNAIVE(co2_bc),
    mean = MEAN(co2_bc),
    drift = RW(co2_bc ~ drift())
  )
```

```
fit_cg_bench <- cg_bc %>%
  model(
    naive = NAIVE(co2_bc),
    snaive = SNAIVE(co2_bc),
    mean = MEAN(co2_bc),
    drift = RW(co2_bc ~ drift())
  )
```

```
fit_befn_bench <- befn_bc %>%
  model(
    naive = NAIVE(co2_bc),
    snaive = SNAIVE(co2_bc),
    mean = MEAN(co2_bc),
    drift = RW(co2_bc ~ drift())
  )
```

```
# =====
# 2) Forecasts (escala transformada), bias_adjust = TRUE
# =====
fc_hid_raw <- forecast(fit_hid_bench, h = h_hid, bias_adjust = TRUE)
fc_ole_raw <- forecast(fit_ole_bench, h = h_ole, bias_adjust = TRUE)
fc_cg_raw <- forecast(fit_cg_bench, h = h_cg, bias_adjust = TRUE)
fc_befn_raw <- forecast(fit_befn_bench, h = h_befn, bias_adjust = TRUE)
```

```
# =====
# 3) Inversão da Box-Cox (.mean / .lower / .upper)
# =====
fc_hid <- inv_bc_across(as_tibble(fc_hid_raw), lambda_hid)
fc_ole <- inv_bc_across(as_tibble(fc_ole_raw), lambda_ole)
fc_cg <- inv_bc_across(as_tibble(fc_cg_raw), lambda_cg)
fc_befn <- inv_bc_across(as_tibble(fc_befn_raw), lambda_befn)
```

```
# =====
# 4) Preparar dataframes finais (observado + previsão)
# =====
fc_hid_df <- fc_hid %>% select(mes, .model, pred = .mean)
fc_ole_df <- fc_ole %>% select(mes, .model, pred = .mean)
fc_cg_df <- fc_cg %>% select(mes, .model, pred = .mean)
fc_befn_df <- fc_befn %>% select(mes, .model, pred = .mean)

hid_join <- hidraulica_teste_2024_25 %>%
  as_tibble() %>%
  select(mes, obs = grupo_hidraulica) %>%
  left_join(fc_hid_df, by = "mes")

ole_join <- oleos_teste_2024_25 %>%
  as_tibble() %>%
  select(mes, obs = grupo_o) %>%
  left_join(fc_ole_df, by = "mes")

cg_join <- cg_teste_2024_25 %>%
  as_tibble() %>%
  select(mes, obs = grupo_cg) %>%
  left_join(fc_cg_df, by = "mes")

befn_join <- befn_teste_2024_25 %>%
  as_tibble() %>%
  select(mes, obs = grupo_befn) %>%
  left_join(fc_befn_df, by = "mes")
```

10) Previsões e geração dos gráficos

```
library(dplyr)
library(tsibble)
library(fable)
library(fabletools)
library(feasts)
library(ggplot2)
library(patchwork)

#-----
# 1) Função genérica para gerar forecast + intervalos
#-----
fc_models <- function(fit, h, lambda) {
  fit |>
  forecast(h = h, bias_adjust = TRUE) |>
  hilo(level = 95) |>
  unpack_hilo('95%') |>
  rename(
```

```

    .lower = `95%_lower`,
    .upper = `95%_upper`
  ) |>
  as_tibble() |>
  mutate(
    .mean = inv_box_cox(.mean, lambda),
    .lower = inv_box_cox(.lower, lambda),
    .upper = inv_box_cox(.upper, lambda)
  )
}

```

```

#-----

```

```

# 2) Configuração dos grupos

```

```

#-----

```

```

groups <- list(
  list(grupo = "Hidráulica",
    lambda = lambda_hid,
    train = hidraulica_treino_2008_2023,
    test = hidraulica_teste_2024_25,
    fits = list(
      arima = fit_hid_arima,
      ets = fit_hid_ets,
      bench = fit_hid_bench
    )),

```

```

  list(grupo = "Óleos",
    lambda = lambda_ole,
    train = oleos_treino_2008_2023,
    test = oleos_teste_2024_25,
    fits = list(
      arima = fit_ole_arima,
      ets = fit_ole_ets,
      bench = fit_ole_bench
    )),

```

```

  list(grupo = "Carvão&Gás",
    lambda = lambda_cg,
    train = cg_treino_2008_2023,
    test = cg_teste_2024_25,
    fits = list(
      arima = fit_cg_arima,
      ets = fit_cg_ets,
      bench = fit_cg_bench
    )),

```

```

  list(grupo = "Renováveis + Nuclear",
    lambda = lambda_befn,
    train = befn_treino_2012_2023,

```



```

    test = befn_teste_2024_25,
    fits = list(
      arima = fit_befn_arima,
      ets = fit_befn_ets,
      bench = fit_befn_bench
    ))
)

#-----
# 3) Cores (tab10) igual ao Python
#-----
model_colors <- c(
  "arima" = "#1f77b4", # azul
  "ets" = "#ff7f0e", # laranja
  "naive" = "#2ca02c", # verde
  "snaive" = "#d62728", # vermelho
  "mean" = "#9467bd", # roxo
  "drift" = "#8c564b" # marrom
)

# Linhas: modelos principais = sólida, benchmarks = tracejada
model_linetype <- c(
  "arima" = "solid",
  "ets" = "solid",
  "naive" = "dashed",
  "snaive" = "dashed",
  "mean" = "dashed",
  "drift" = "dashed"
)

# helper simples pra pegar a coluna do grupo como 'obs'
get_grupo_obs <- function(df) {
  col <- grep("grupo", names(df), value = TRUE)
  if (length(col) == 0) {
    stop("Nenhuma coluna contendo 'grupo' encontrada.")
  }
  df[[col[1]]]
}

plots <- list()

#-----
# 4) Loop para gerar gráficos no estilo Python final
#-----
for (g in groups) {

  grupo <- g$grupo
  lambda <- g$lambda

```

```

train  <- g$train
test   <- g$test
fits   <- g$fits
h      <- nrow(test)

# Forecasts de cada modelo
fc_arma <- fc_models(fits$arma, h, lambda)
fc_ets  <- fc_models(fits$ets, h, lambda)
fc_bench <- fc_models(fits$bench, h, lambda)

fc_all <- bind_rows(fc_arma, fc_ets, fc_bench) |>
  mutate(
    mes = as.Date(mes),
    .model = as.character(.model) # garante compatível com escalas manuais
  )

# Histórico (últimos 36 meses do treino)
hist_obs <- train |>
  mutate(
    mes = as.Date(mes),
    obs = get_grupo_obs(cur_data_all())
  ) |>
  dplyr::slice_tail(n = 36)

# Série real (teste)
real_obs <- test |>
  mutate(
    mes = as.Date(mes),
    obs = get_grupo_obs(cur_data_all())
  )

# -----
# Gráfico Estilo Python
# -----
p <- ggplot() +

  # Histórico em cinza
  geom_line(
    data = hist_obs,
    aes(x = mes, y = obs),
    colour = "grey75",
    linewidth = 1.2,
    alpha = 0.8
  ) +

  # Série REAL (preto grosso)
  geom_line(
    data = real_obs,

```

```

    aes(x = mes, y = obs),
    colour = "black",
    linewidth = 1.6
  ) +

  # Previsões (todas)
  geom_line(
    data = fc_all,
    aes(x = mes, y = .mean, colour = .model, linetype = .model),
    linewidth = 1.1
  ) +

  scale_colour_manual(values = model_colors) +
  scale_linetype_manual(values = model_linetype) +

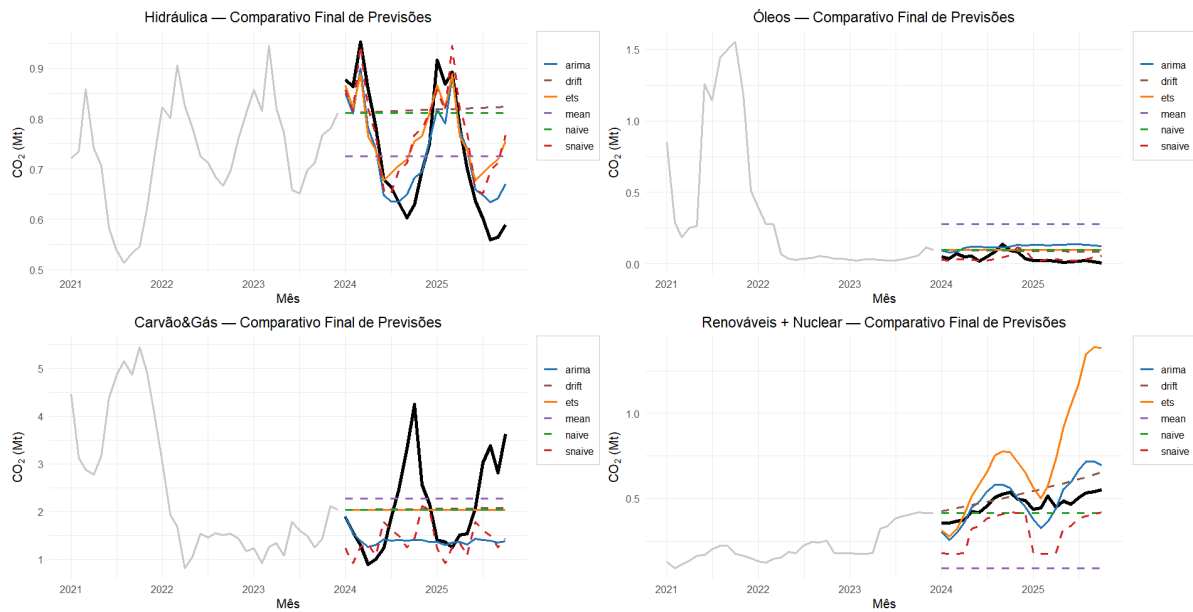
  labs(
    title = paste0(grupo, " — Comparativo Final de Previsões"),
    x = "Mês",
    y = expression("CO"[2] * " (Mt)"),
    colour = "",
    linetype = ""
  ) +

  theme_minimal(base_size = 13) +
  theme(
    legend.position = c(1.02, 1),
    legend.justification = c(0, 1),
    legend.background = element_rect(fill = "white", colour = "grey80"),
    plot.margin = margin(5.5, 80, 5.5, 5.5),
    plot.title = element_text(hjust = 0.5)
  )

  # guarda usando o nome do grupo
  plots[[grupo]] <- p
}

#-----
# 5) Exibir tudo em 2x2
#-----
(p1 <- plots[[1]] | plots[[2]])
(p2 <- plots[[3]] | plots[[4]])
p1 / p2

```



11) Identificação dos melhores modelos para cada série temporal por grupo:

```
calc_metrics <- function(df) {
  df %>%
    summarise(
      RMSE = sqrt(mean((obs - pred)^2, na.rm = TRUE)),
      MAE = mean(abs(obs - pred), na.rm = TRUE),
      MAPE = mean(abs((obs - pred) / obs), na.rm = TRUE) * 100
    )
}
```

```
metrics_list <- list()
```

```
for(g in groups) {
```

```
  grupo <- g$grupo
  lambda <- g$lambda
  train <- g$train
  test <- g$test
  fits <- g$fits
  h <- nrow(test)
```

```
  # forecasts já transformados para a escala original
  fc_arima <- fc_models(fits$arima, h, lambda)
  fc_ets <- fc_models(fits$ets, h, lambda)
  fc_bench <- fc_models(fits$bench, h, lambda)
```

```
  fc_all <- bind_rows(fc_arima, fc_ets, fc_bench) %>%
    mutate(mes = as.Date(mes))
```

```

# Observado (apenas teste)
obs_test <- test %>%
  mutate(
    mes = as.Date(mes),
    obs = dplyr::coalesce(
      across(contains("grupo")) |> unlist()
    )
  ) %>%
  select(mes, obs)

# juntar previsões x observados
joined <- fc_all %>%
  left_join(obs_test, by = "mes") %>%
  rename(pred = .mean)

# calcular métricas por modelo
metrics <- joined %>%
  group_by(.model) %>%
  calc_metrics() %>%
  mutate(grupo = grupo) %>%
  select(grupo, modelo = .model, RMSE, MAE, MAPE)

metrics_list[[grupo]] <- metrics
}

# resultado final
metrics_all <- bind_rows(metrics_list) %>%
  arrange(grupo, RMSE)

print(metrics_all)

> print(metrics_all)
# A tibble: 24 x 5
   grupo      modelo  RMSE    MAE  MAPE
  <chr>    <chr>    <dbl>  <dbl> <dbl>
1 Carvão&Gás drift    0.917  0.764  41.3
2 Carvão&Gás ets      0.923  0.768  41.1
3 Carvão&Gás naive    0.923  0.768  41.1
4 Carvão&Gás mean     0.934  0.818  48.3
5 Carvão&Gás snaive    1.13   0.805  32.2
6 Carvão&Gás arima     1.16   0.808  30.4
7 Hidráulica arima     0.0521 0.0439  6.20
8 Hidráulica snaive    0.0803 0.0648  9.82
9 Hidráulica ets       0.0828 0.0678 10.3
10 Hidráulica mean     0.124  0.111 15.3

best_models <- metrics_all %>%

```

```
group_by(grupo) %>%
slice_min(RMSE, n = 1, with_ties = FALSE)
```

```
print(best_models)
```

```
> print(best_models)
# A tibble: 4 × 5
# Groups:   grupo [4]
  grupo          modelo  RMSE    MAE    MAPE
  <chr>         <chr>    <dbl>  <dbl>  <dbl>
1 Carvão&Gás    drift    0.917  0.764  41.3
2 Hidráulica    arima    0.0521 0.0439  6.20
3 Renováveis + Nuclear naive    0.0781 0.0682  14.2
4 Óleos         snaive    0.0348 0.0265 108.
```

12) Geração dos gráfico com a série temporal hidráulica com o melhor modelo ajustado (ARIMA):

```
library(dplyr)
library(tsibble)
library(fable)
library(fabletools)
library(feasts)
library(ggplot2)
```

```
# h = tamanho do conjunto de teste
h_hid <- nrow(hidraulica_teste_2024_25)
```

```
# -----
# 1) Forecast ARIMA vencedor + IC 95% (escala original)
# -----
fc_hid <- fit_hid_arima |>
  forecast(h = h_hid, bias_adjust = TRUE) |>
  hilo(95) |>
  unpack_hilo(`95%`) |>
  rename(
    .lower = `95%_lower`,
    .upper = `95%_upper`
  ) |>
  as_tibble() |>
  mutate(
    .mean = inv_box_cox(.mean, lambda_hid),
    .lower = inv_box_cox(.lower, lambda_hid),
    .upper = inv_box_cox(.upper, lambda_hid),
    mes = as.Date(mes)
  )
```

```

# -----
# 2) Séries observadas (treino + teste)
# -----
obs_full <- dataset_st |>
  select(mes, obs = grupo_hidraulica) |>
  mutate(mes = as.Date(mes))

obs_test <- hidraulica_teste_2024_25 |>
  select(mes, obs = grupo_hidraulica) |>
  mutate(mes = as.Date(mes))

# -----
# FILTRO PARA PLOTAR APENAS A PARTIR DE 2024-01-01
# -----
obs_full <- obs_full %>% filter(mes >= as.Date("2024-01-01"))
obs_test <- obs_test %>% filter(mes >= as.Date("2024-01-01"))
fc_hid <- fc_hid %>% filter(mes >= as.Date("2024-01-01"))

# -----
# 3) Gráfico Estilo Python (igual ao notebook)
# -----
p_hid <- ggplot() +

  # Histórico em cinza claro
  geom_line(
    data = obs_full,
    aes(x = mes, y = obs),
    colour = "grey75",
    linewidth = 1.2,
    alpha = 0.8
  ) +

  # Série REAL de teste (preto grosso)
  geom_line(
    data = obs_test,
    aes(x = mes, y = obs),
    colour = "black",
    linewidth = 1.6
  ) +

  # Faixa do IC (em azul claro = tab10 azul com alta transparência)
  geom_ribbon(
    data = fc_hid,
    aes(x = mes, ymin = .lower, ymax = .upper),
    fill = tab10[1],
    alpha = 0.15
  ) +

```

```

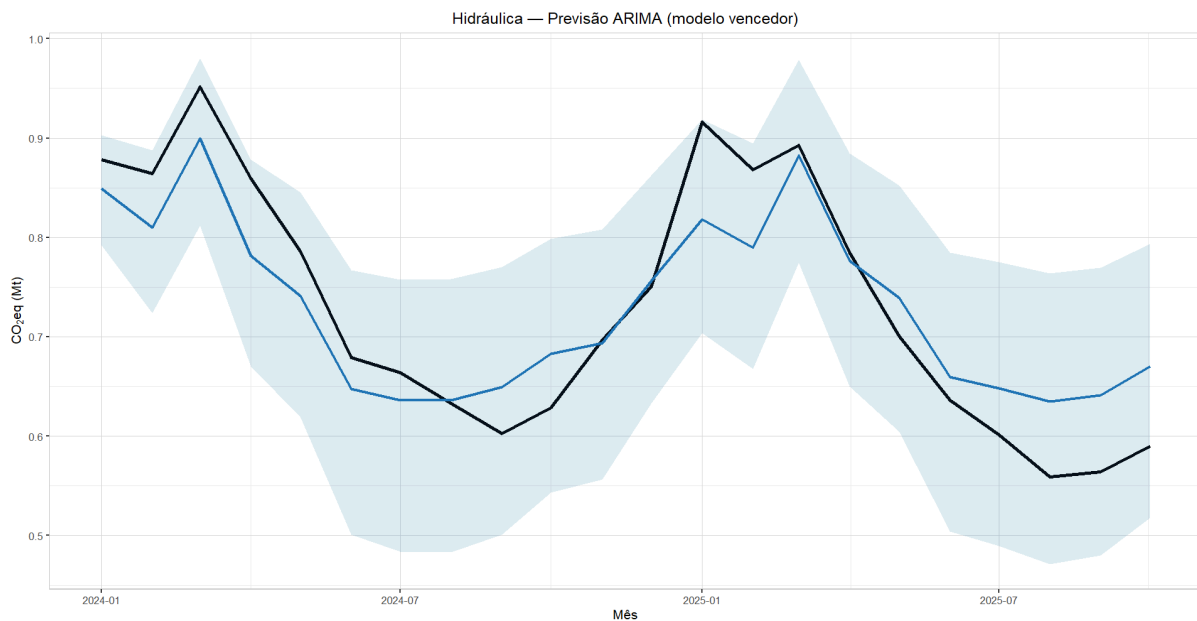
# Linha de previsão em azul (tab10)
geom_line(
  data = fc_hid,
  aes(x = mes, y = .mean),
  colour = tab10[1],
  linewidth = 1.3
) +

labs(
  title = "Hidráulica — Previsão ARIMA (modelo vencedor)",
  x = "Mês",
  y = expression("CO"[2] * "eq (Mt)"),
  colour = ""
) +

theme(
  plot.title = element_text(hjust = 0.5),
  plot.subtitle = element_text(hjust = 0.5),
  legend.position = "none", # igual ao Python
  panel.grid.minor = element_line(colour = "grey92", linewidth = 0.25),
  panel.grid.major = element_line(colour = "grey85", linewidth = 0.40)
)

print(p_hid)

```



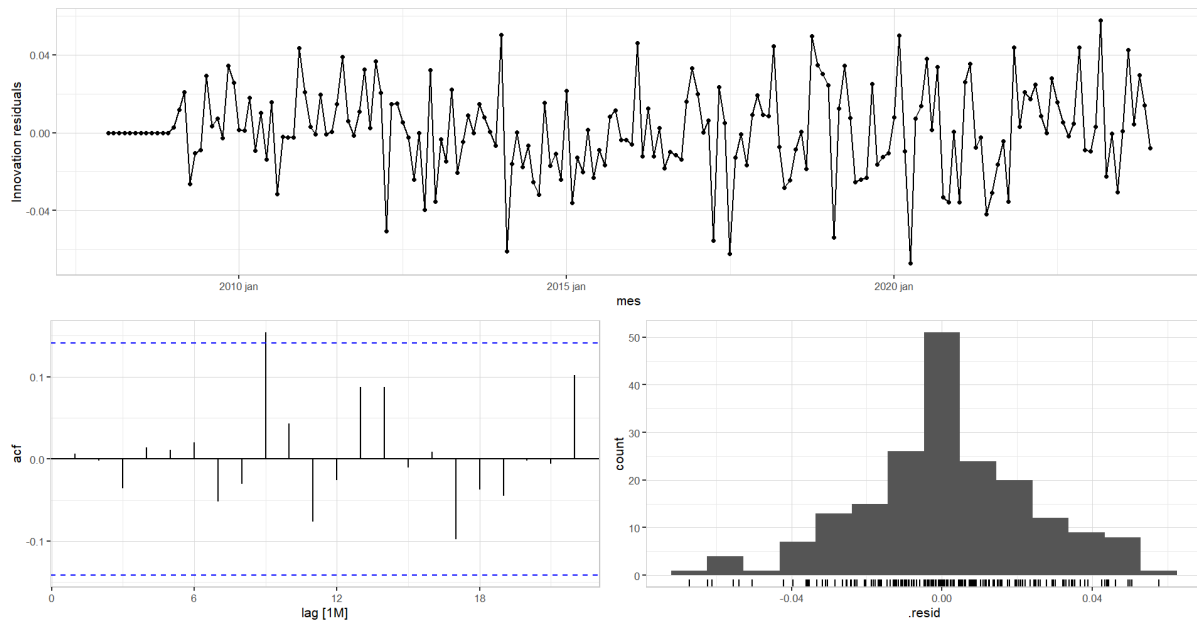
13) Diagnóstico dos resíduos e teste Ljung Box


```
fit_hid_arima |> gg_tsresiduals()
```

```
fit_hid_arima |>
```

```
  augment() |>
```

```
  features(.innov, ljung_box, lag = 24)
```



```
+   features(.innov, ljung_box, lag = 24)
```

```
# A tibble: 1 × 3
```

```
  .model lb_stat lb_pvalue
```

```
  <chr>   <dbl>   <dbl>
```

```
1 arima    23.2    0.507
```