How has COVID-19 affected the French electricity load curve?

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Motivation

- **Electricity:** 2nd French energy source (26% of total energy consumption in 2023 (SEDS, 2024))
- **COVID-19: exogenous test** on the power system
  - Sudden, non-economic restrictions (lockdowns, telework)
- **Analytical goal:** moving beyond a historical event
  - Develop a **robust causal methodology**
  - Measure the effect of abrupt social/policy shocks on **energy demand**
- **Operational relevance:** converting crisis into a roadmap
  - Anticipate **future shocks** (permanent remote work, geopolitical crises)
  - Quantification for **grid resilience** (load shedding risks, resource planning)

Research question

How did national COVID-19 restrictions reshape the French electricity load curve?

Related literature

- **Electricity consumption declines:** global consensus ▸ Lit. Rev.
- **Sectoral shift:** industrial ↓ vs. residential ↑
  - **Industry/commerce** ↓ (Bover et al., 2023; AI et al., 2022)
  - **Residential** ↑ (Abdeen et al., 2021; Bover et al., 2023)
- **Daily load curve changes → reshaping**
  - **Overall curve** ↓ (Berezvai et al., 2022; Narajewski et al., 2020)
  - **Peak flattening/shift:** morning and evening peaks were **smoothed** (Spain) (Santiago et al., 2021)
  - **Midday peak in residential ↑:** afternoon consumption significantly increased due to Work From Home (WFH)
    Ex: afternoon peak ↑ 13% to 53% in the US (Li et al., 2022); Midday load ↑ 46% in Canada (Rouleau et al., 2021)

Contributions

Research gaps

- **Geographical focus:** lack of dedicated within-country analysis for France, with panel averages masking national specificity
- **Missing data:** need for high-frequency (half-hourly) and sectoral data

Three-fold contribution

1. **France-specific analysis:** first dedicated within-country analysis for the French system
2. **High-frequency analysis (within-a-day):** half-hourly analysis of the load curve and its variation (weekdays vs. weekends)
3. **Five-sector analysis:** first insights across all five consumption sectors

This paper

What do we do?

- **Overall evaluation:** measure the impact of national restrictions on **electricity consumption** ▸ Results
- **Within-a-day analysis (load curve):** investigate how these measures **reshaped the load curve**, focusing on variations across different hours of the day
- **Temporal heterogeneity:** compare the impact between **weekdays** and **weekends**
- **Sectoral analysis:** examine the demand response by **sector** (residential, industry, tertiary)

How do we do it?

- High-frequency data: half-hourly electricity consumption
- Differences (DiD) to isolate the causal impact by comparing COVID-19 days to their historical equivalents

Data sources

- **Electricity consumption data:** national half-hourly load data (2015-2021) provided by **RTE** ▸ Consumption evolution
- **Policy measures: Oxford Stringency Index (OSI)**
  ▸ OSI components ▸ OSI formula ▸ OSI evolution
- **Sectoral consumption:** generated for residential, industry, tertiary, transport, and agriculture based on annual ministry reports

Empirical strategy

We use the following DiD equation, for half-hour t of day d of year y: Parallel trends

$$Y_{tdy} = \alpha + \beta_1 \left(OSI_{dy} \times 1\{2020 \leq y \leq 2021\} \right) + \beta_2 \mathrm{X}_{tdy} + \mu_d + \varepsilon_{tdy}$$

where

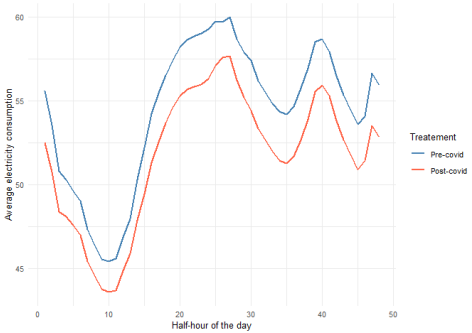
$$1\{2020 \leq y \leq 2021\} = \begin{cases} 1 & \text{if the year } y \text{ falls between 2020 and 2021,} \\ 0 & \text{otherwise} \end{cases}$$

- Y_{tdy} is electricity consumption at half-hour t of day d of year y
- OSI_{dy} is the value of the Oxford Stringency Indicator at day d of year y
- X_{tdy} a vector of controls List of controls
- μ_d are day fixed effects
- ε_{tdy} is the idiosyncratic error term

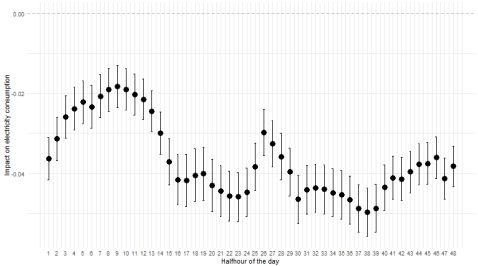
Level and shape of the load curve

1. Global electricity load curve shifts
2. Within-a-day heterogeneity
   - 2.1 Whole-family-at-home effect on load curve
   - 2.2 Day-of-week heterogeneity

1. Global electricity load curve shifts



(a) Average 2020–21 vs. 2015–19 half-hourly electricity consumption

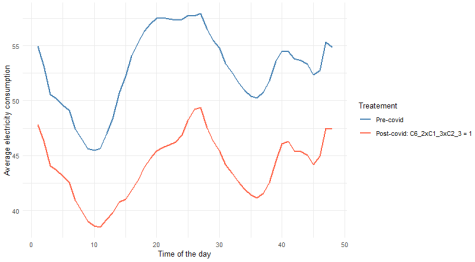


(b) Impact of COVID-19 restrictions on French electric load curve (DiD estimates)

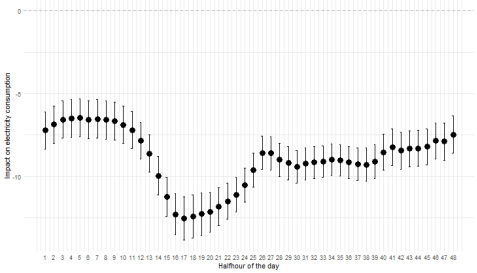
Figure: Overview of COVID-19 impacts on France's daily load curve

Table: Definition and Interpretation of Lockdown Stringency Scenarios

Scenario	Interaction	Description
Whole family at home	$C6 = 2 \times C1 = 3 \times C2 = 3$	The most severe situation: obligation to stay home ($C6 = 2$) and school closure ($C1 = 3$) and mandatory closure of non-essential sectors ($C2 = 3$).



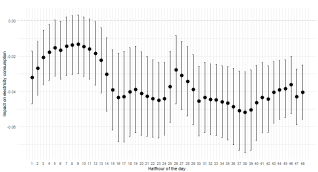
(a) "Whole-family-at-home" load curve compared to same date in year previous to COVID-19 (2015–2019)



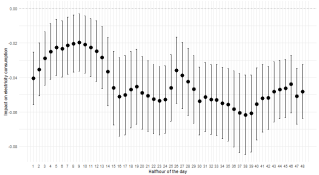
(b) Effect of "Whole-family-at-home" on the French load curve (DiD estimates)

Figure: Effect of "Whole-family-at-home" on French electric load curve

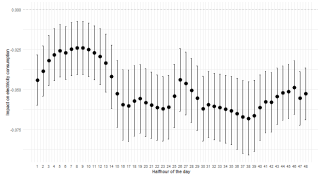
2.2 Day-of-week heterogeneity (1/2)



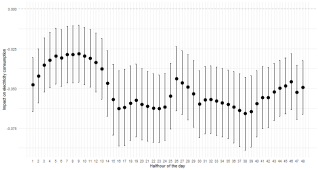
(a) Mondays



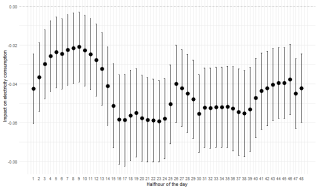
(b) Tuesdays



(c) Wednesdays



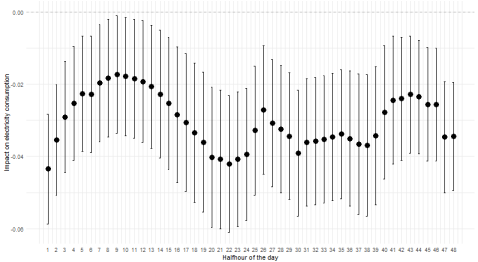
(d) Thursdays



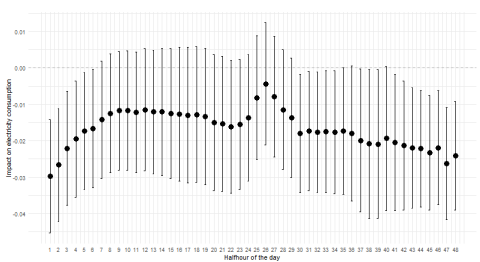
(e) Fridays

Figure: Effect of stringency on half-hourly consumption by weekday (DiD estimates)

2.2 Day-of-week heterogeneity (2/2)



(a) Saturdays



(b) Sundays

Figure: Comparison of the effect on Saturdays and Sundays (DiD estimates)

Conclusions

- **Global net negative effect** on consumption specially in peak of economic activity moments
- **Weekend vs weekdays:** very strong effect negative effect in weekdays and marginal negative effect in weekends but no effect on Sunday

To do list

1. Evaluate the consequences on mix generation and price
2. Wholesale price becomes more volatile?
3. Proposition of a theoretical framework

Thank you!

Related literature: Global consensus on electricity consumption decline

- **Global consensus** (Jiang et al., 2021; Werth et al., 2021)
- **Europe: stringency and industrial impact** (Bahmanyar et al., 2020)
  - **Italy** (Ghiani et al., 2020), **Spain/Portugal** (Santiago et al., 2021; Cerqueira et al., 2023), **Turkey** (Industrial focus, Cihan et al., 2022)
- **Asia & Americas: deep and documented drops**
  - Asia: **China** (Wang et al., 2021; Li et al., 2022) and **South Korea** (Kang et al., 2021) documented major outbreaks leading to sharp decreases
  - Americas/Oceania: studies confirmed significant drops in the **US** (Gillingham et al., 2020), **Brazil** (de Carvalho et al., 2021), and **New Zealand** (Wen et al., 2022)
- **Synthesis (Jiang et al., 2021):** the negative impact is **robust** across diverse regions (France, Germany, Italy, Spain, China, India) with drops often exceeding 10% in peak months

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Results: Overall effect

Table: Impact of COVID-19 restrictions on French half-hourly electricity consumption, OLS and DiD estimates

	OLS	DID	DID
Dep. var.:	National Half-hour electricity consumption		
OSI	-0.03856^{***}		
	(0.00069)		
COVID		-2.01383^{***}	
		(0.15788)	
COVID×OSI			-0.03851^{***}
			(0.00065)
Controls	Yes	Yes	Yes
Observations	122 736	122 736	122 736
R^2	0.7080	0.336	0.2127

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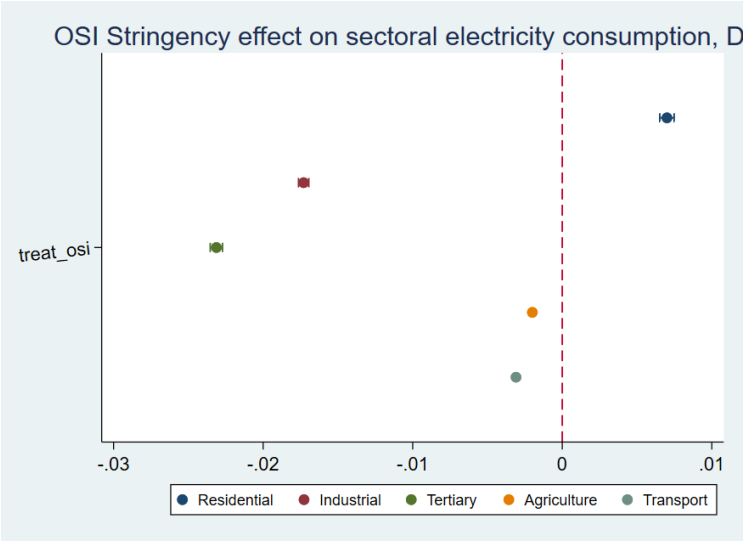
Heterogeneity analyses

1. **Sectoral analysis**

2. **Household composition effect:** assess how the effect of restrictions varies across different household composition (e.g., presence of children/parents)

3. **Weekday analysis**

1. Sectoral analysis



2.1. Household Composition Scenarios

Table: Definition and Interpretation of Lockdown Stringency Scenarios

Scenario	Interaction	Description
Children at home	$C6 = 2 \times C1 = 3$	Days with obligation to stay at home ($C6 = 2$) and a mandatory school closure for all levels ($C1 = 3$).
Parents at home	$C6 = 2 \times C2 = 3$	Days with obligation to stay at home ($C6 = 2$) and a mandatory closure of all non-essential sectors ($C2 = 3$).
Whole family at home	$C6 = 2 \times C1 = 3 \times C2 = 3$	The most severe situation: obligation to stay home ($C6 = 2$) and school closure ($C1 = 3$) and mandatory closure of non-essential sectors ($C2 = 3$).

2.2. Household composition effect

Impact of household composition at home on French half-hourly electricity consumption, DiD estimates

	Dep. var.: National half-hourly electricity consumption		
Children at home	-7.12^{***}		
	(0.26)		
Parents at home		-6.64^{***}	
		(0.18)	
Whole family at home			-8.80^{***}
			(0.16)
Controls	Yes	Yes	Yes
Observations	18,480	36,288	18,480
Within R^2	0.378	0.312	0.376
F-statistic	861.3	912.5	854.8

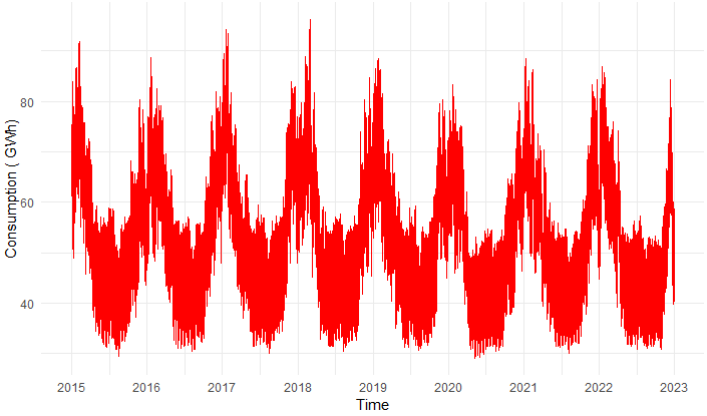
Notes: Robust standard errors are in parentheses. *** $p < 0.01$. The table presents the DiD coefficients of the interaction term

3. Weekday analysis

Table: Impact of COVID-19 restrictions on French half-hourly electricity consumption according to the day of the week, DiD estimates

	Mon	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
Dep. var.:	National Half-hour electricity consumption						
COVID×OSI	−0.008**	−0.019***	−0.032***	−0.036***	−0.029***	−0.010***	0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.022)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,520	17,520	17,520	17,568	17,568	17,520	17,520
R^2	0.00771	0.0050	0.0105	0.0201	0.0136	0.0056	0.0008

Appendix: RTE half-hourly load sample



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Appendix: Oxford Stringency Index (OSI) calculation

OSI is the average of K sub-indices (I_{jit}):

$$I_{it} = \frac{1}{K} \sum_{j=1}^{K} I_{jit}$$

Sub-index calculation (normalization to 0-100):

$$I_{jit} = 100 \times \frac{V_{jit} - 0.5 \times (F_j - f_{jit})}{N_j}$$

where:

- V_{jit} is the recorded ordinal policy score (e.g., 0 to 3 for C1: School Closures)
- N_j is the maximum possible score for policy j
- F_j is a binary flag (1 if policy j includes an optional flag, 0 otherwise)
- f_{jit} records whether the optional flag is active (e.g., policy applies only to a specific subpopulation) Back

Appendix: Oxford Stringency Index (OSI) components

Table: Oxford Stringency Index characteristics Back

Sub-index	Index name	Modality explanation
C1	School closures	0 - No restriction / 3 - Mandatory closure (all levels)
C2	Workplace closing	0 - No restriction / 3 - Mandatory closure (except essential services)
C3	Cancel public events	0 - No restriction / 2 - Mandatory cancellation
C4	Restrictions on gathering size	0 - No restrictions / 4 - <10 people
C5	Close public transport	0 - No restriction / 2 - Mandatory closure or major ban
C6	Stay at home requirements	0 - No restriction / 3 - Strict obligation (minimal exceptions)
C7	Restrictions on internal movement	0 - No restriction / 2 - Ban on internal travel (except exceptional circumstances)
C8	Restrictions on international travel	0 - No restriction / 4 - Complete closure of borders
H1	Public information campaign	0 - No official campaign / 2 - Coordinated information campaign

Appendix: OSI value evolution

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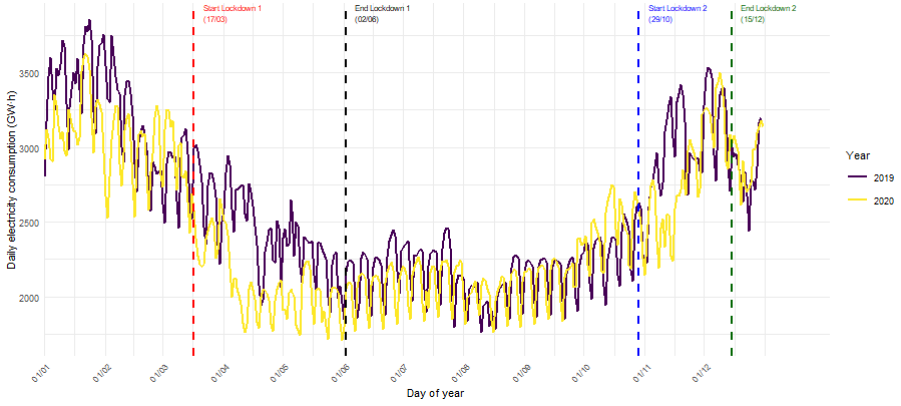
Appendix: Parallel trend



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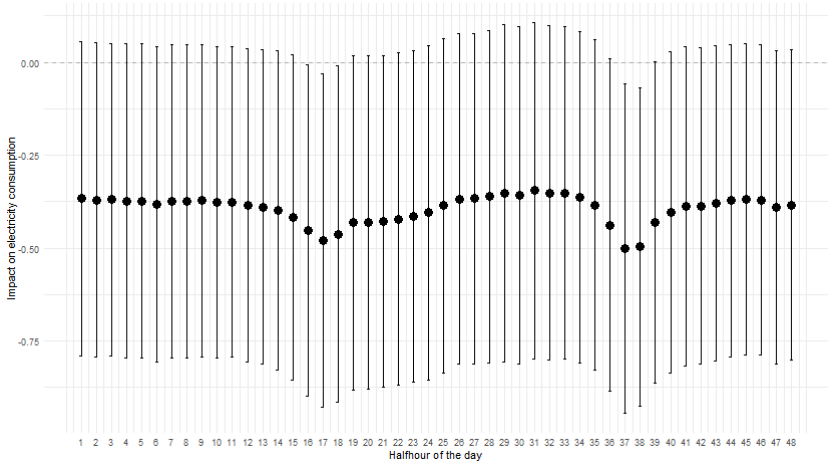
Appendix: Within-a-day parallel trend



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Appendix: List of controls

To control for seasonality, we include as control variables:

- **the day of the week:** binary variables from Monday to Sunday,
- **the month of the year:** binary variables for each month
- **the dates of public holidays:** binary variable for New Year's Day (January 1), Labor Day (May 1), Victory in Europe Day (May 8), Bastille Day (July 14), Assumption of Mary (August 15), All Saints' Day (November 1), Armistice Day (November 11), and Christmas Day (December 25)

We do not include climate controls: the energy consumption data are already adjusted for climate effects; our sample is therefore decorrelated from weather variation.

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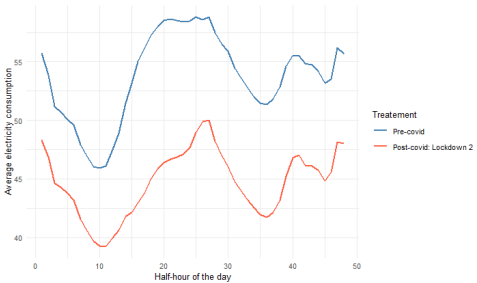
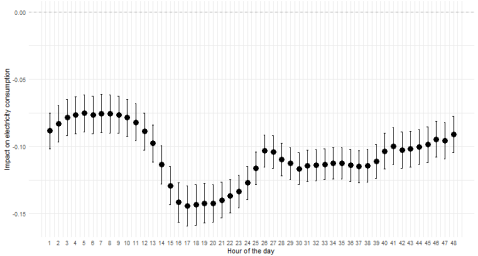
Appendix: Lockdown analysis (1/3)

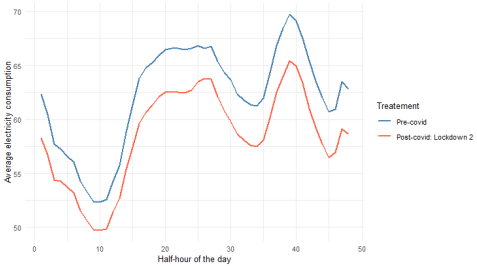


(a) Effect of COVID-19 on load curve during lockdown 1

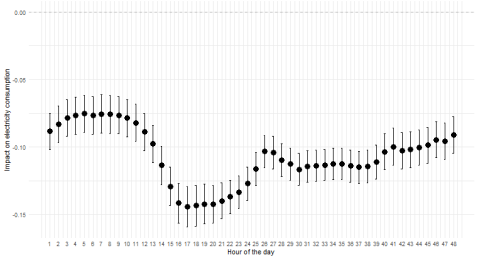


(b) Load curve during Lockdown 1 vs. pre-COVID

Appendix: Lockdown analysis (2/3)

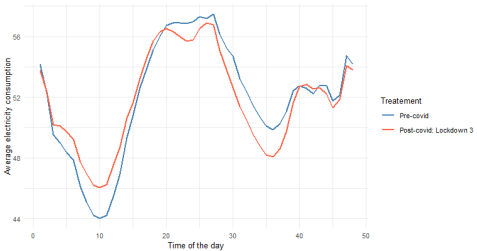


(a) Load curve during lockdown 2 vs. pre-COVID

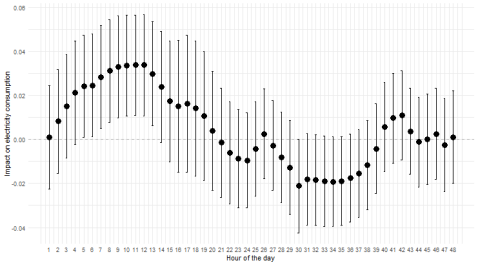


(b) Effect of COVID-19 on load curve during lockdown 2

Appendix: Lockdown analysis (3/3)



(a) Effect of COVID-19 on load curve during lockdown 3



(b) Load curve during lockdown 3 vs. pre-COVID