# RENEWABLE ENERGY AND ITS IMPACT ON THERMAL GENERATION

## 7TH ATLANTIC WORKSHOP ON ENERGY AND ENVIRONMENTAL ECONOMICS, A TOXA, GALICIA (SPAIN)

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## POWER SYSTEMS WITH RENEWABLES

- Competitive advantage of renewables in terms of marginal cost
    - Thermal generation units at risk
    - Which specific units affected depends on the amount of installed renewable capacity
    - Result: Lower average spot market prices [see, e.g., Green and Vasilakos, 2010, Woo et al., 2011, Würzburg et al., 2013, Paraschiv et al., 2014, Clò et al., 2015], and also change in price variance [see, e.g., Wozabal et al., 2015]

- Renewables lead to less emissions in the power sector. Effects highly heterogeneous [see, e.g., Novan, 2015, Graff Zivin et al., 2014, Cullen, 2013]
    - Spatial: Across markets, depending on the power generation mix
    - Within-markets
        - Temporal: Across time/demand
        - Impact depends on the amount of installed renewable capacity

## POWER SYSTEMS WITH RENEWABLES (CONT'D)

- What about emission factors?
    - Short-run
        - Excessive load-cycling may lead to higher emissions relative to output
        - Part-load operation (lower capacity factor)
    - Long-run: Market pressure may lead to investment in more efficient/flexible thermal plants

### WHAT'S THE EXACT EFFECT?

Katzenstein and Apt [2009]: $CO_2$ emissions may be 20% higher than expected if power fluctuations caused no additional emissions

# POWER SYSTEMS WITH RENEWABLES (CONT'D)

- Empirical study of the Italian power market
- Intermittent renewables: Wind and photovoltaics (PV)
- Time span: 2005 to 2014
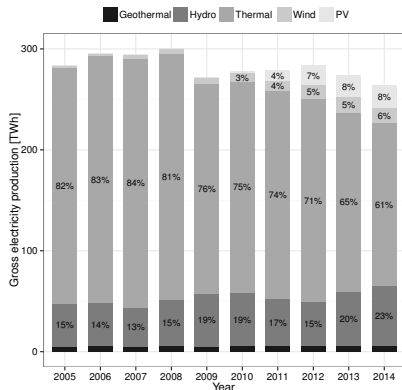


### RESEARCH QUESTION

How do thermal plant emission factors change if the system is challenged by intermittent renewables?

# COMBING VARIOUS DATA SOURCES

1. Gestore dei Mercati Energetici (GME)
   - Accepted spot market bids (day-ahead,intra-day, and balancing), hourly on generation unit level
2. EU ETS Transaction log
   - Verified $CO_2$ emissions, yearly on installation level
3. REF-E (Italian consulting company)
   - Power plant database
4. TERNA (TSO), ENTSO-E
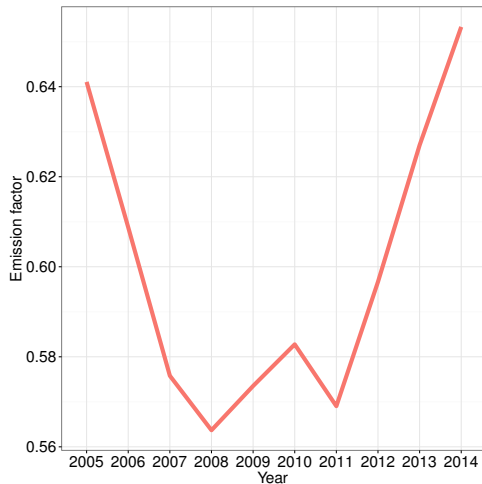   - Data on infeed from renewables, consumption, imports/exports

# MATCHING

- 93/98 matched installations (219 generators)
- 73% of Italy's total thermal production
- 96% of Italy's emissions in the power sector
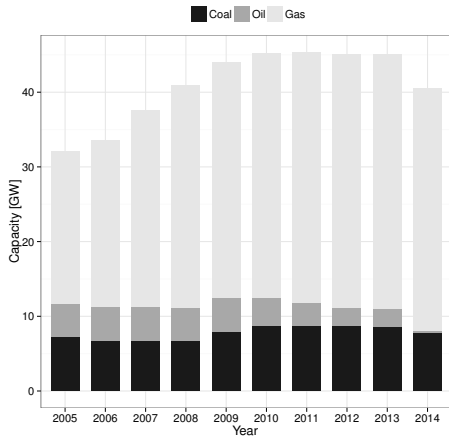
# EMISSION FACTORS

- $\forall i = 1, \ldots, 93$ and $t = 2005, \ldots, 2014$
- Emissions: $E_{i,t}$
- Awarded spot market quantities: $Q_{i,t}$
- Emission factor: $\phi_{i,t} = \frac{E_{i,t}}{Q_{i,t}}$

## ECONOMETRIC MODEL

$$\ln(\phi_{i,t}) = \beta_1 \ln(D'_t) + \beta_2 \ln(R_t) + \beta_3 X_{i,t} + \epsilon_{i,t} \qquad (1)$$

- System-specific explanatory variable: $D'_t = (D_t - H_t - I_t)$ and generated electricity from wind and photovoltaics ($R_t$)
- Installation-specific explanatory variables: FE for each installation, commissioning year $Y_{i,t}$, and the fuel cost structure $F_{i,t}$, ($X_{i,t} = (Y_{i,t}, F_{i,t})$)
- $\epsilon_{i,t} = \mu_i + \nu_{i,t}$, whereas $\mu_i$ denotes the unobservable installation-specific fixed effect and $\nu_{i,t} \sim \text{IID}(0, \sigma_\nu^2)$

## IDENTIFICATION

1. Baseline regression using all thermal installations (all)
2. Only base-load installations (base)
3. Only peak-load installation (peak)
4. Only installations which have changed capacity during the period (new)
5. Accounting for Italy's zonal market (zonal)

# REGRESSION RESULTS

|  | (all) | (base) | (peak) | (new) | (zonal) |
|---|---|---|---|---|---|
| Residual demand | −0.119 | −0.093 | 0.102 | −.082 | |
| | (0.096) | (0.116) | (0.195) | (0.078) | |
| Renewables | 0.025** | 0.022** | 0.051* | 0.021 | |
| | (0.008) | (0.008) | (0.021) | (0.011) | |
| Commissioning year | −27.345*** | −18.953** | −7.626 | −26.226*** | −26.135*** |
| | (6.076) | (5.202) | (10.120) | (6.508) | (6.499) |
| Fuel cost structure | −0.005 | −0.031 | 0.044 | 0.016 | 0.003 |
| | (0.031) | (0.042) | (0.062) | (0.054) | (0.003) |
| Residual demand (zone) | | | | | −0.107* |
| | | | | | (0.029) |
| Renewables (zone) | | | | | −0.010* |
| | | | | | (0.004) |
| $R^2$ within/between | 0.23/0.50 | 0.17/0.59 | 0.13/0.08 | 0.23/0.39 | 0.22/0.49 |
| Observations | 723 | 510 | 213 | 249 | 723 |
| Installations | 89 | 65 | 27 | 28 | 89 |

*Notes:* Robust standard errors clustered by installation reported in parentheses. Asterisks indicate statistical significance at 5% (*), 1% (**), and 0.1% (***) levels.

# SO WHAT?

- Share of increased inefficiency in comparison to offset emissions?
  - First order effect $((\mathrm{d}\ln(E_{i,t}))/(\mathrm{d}\ln(R_t)) = \beta_2')$

|  | (all) | (base) | (peak) | (new) | (zonal) |
|---|---|---|---|---|---|
| $\beta_2$ | 0.025 | 0.022 | 0.051 | 0.021 | 0.010 |
| $\beta_2'$ | $-0.315$ | $-0.250$ | $-0.686$ | $-0.369$ | $-0.113$ |
| $\beta_2'/(\beta_2' - \beta_2)$ | 93% | 92% | 93% | 95% | 92% |

# DISCUSSION AND POLICY CONSEQUENCES

- Renewable production *increases* emission factors of the average plant
    - (Absolute) effect even stronger when considering only peak-load plants
    - Evidence of long-term effect (coefficient of renewables not statistically significant if sample restricted to new plants)
- Our estimates are less pessimistic than in Katzenstein and Apt [2009]; System view is important (burden sharing!)
- Policy consequences
    - System-specific perspective: Storage, transmission, demand side management (load shifting)
    - Installation-specific perspective: Better design of thermal plants

THANK YOU FOR YOUR ATTENTION!

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WORKING PAPER AVAILABLE!

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