

# Probabilistic harmonic injection models of residential loads

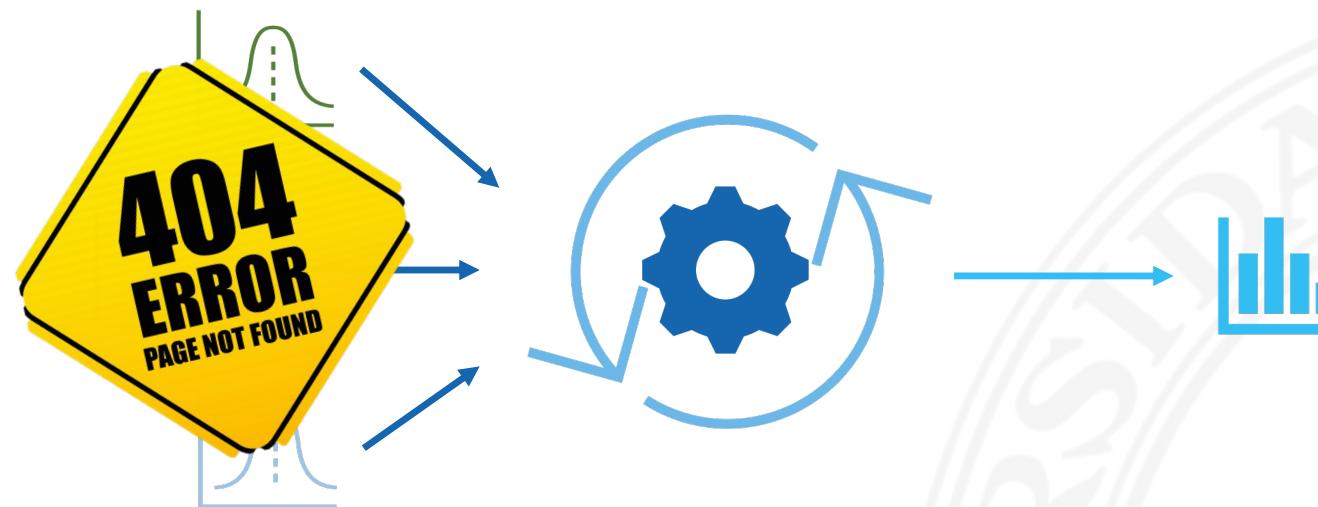
Araceli Hernández Bayo • Pablo Rodríguez Pajarón



# Motivation

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Assessment of harmonic distortion of residential distribution networks



**Input:**  
Probabilistic residential  
harmonic models

Monte Carlo harmonic  
injection problem

**Output:**  
Statistics on harmonic  
voltages

# Contents

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1 Measurement-based models

2 Bottom-up models

# Contents

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1 Measurement-based models

2 Bottom-up models

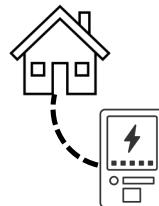
# 1. Measurement-based models

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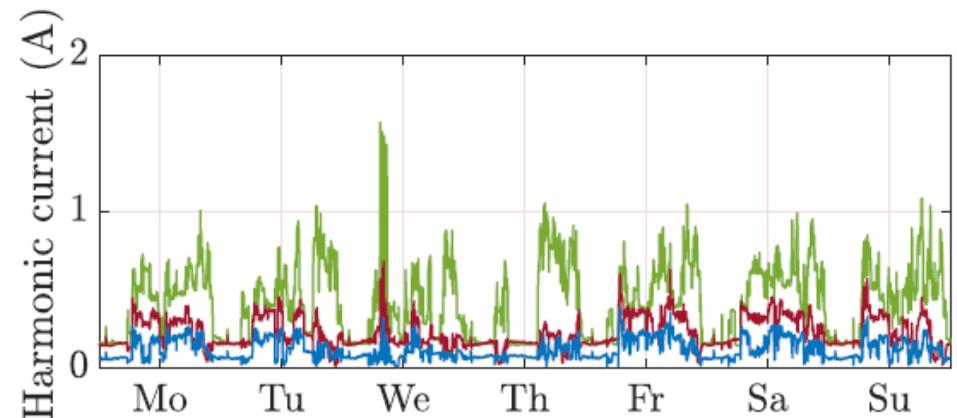
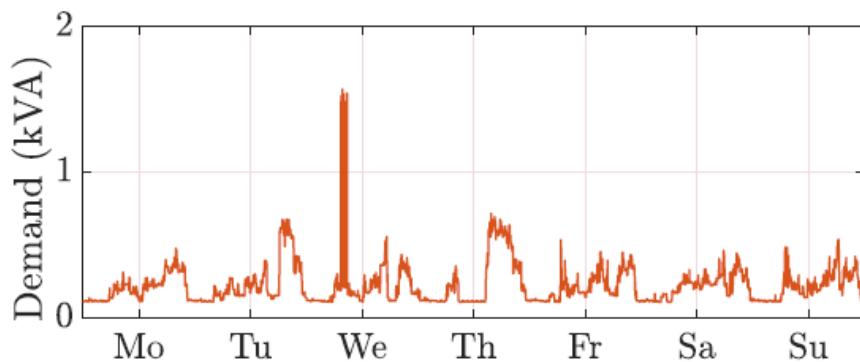
Goal: Modeling residential harmonic injections by means of probability distributions

# 1. Measurement-based models

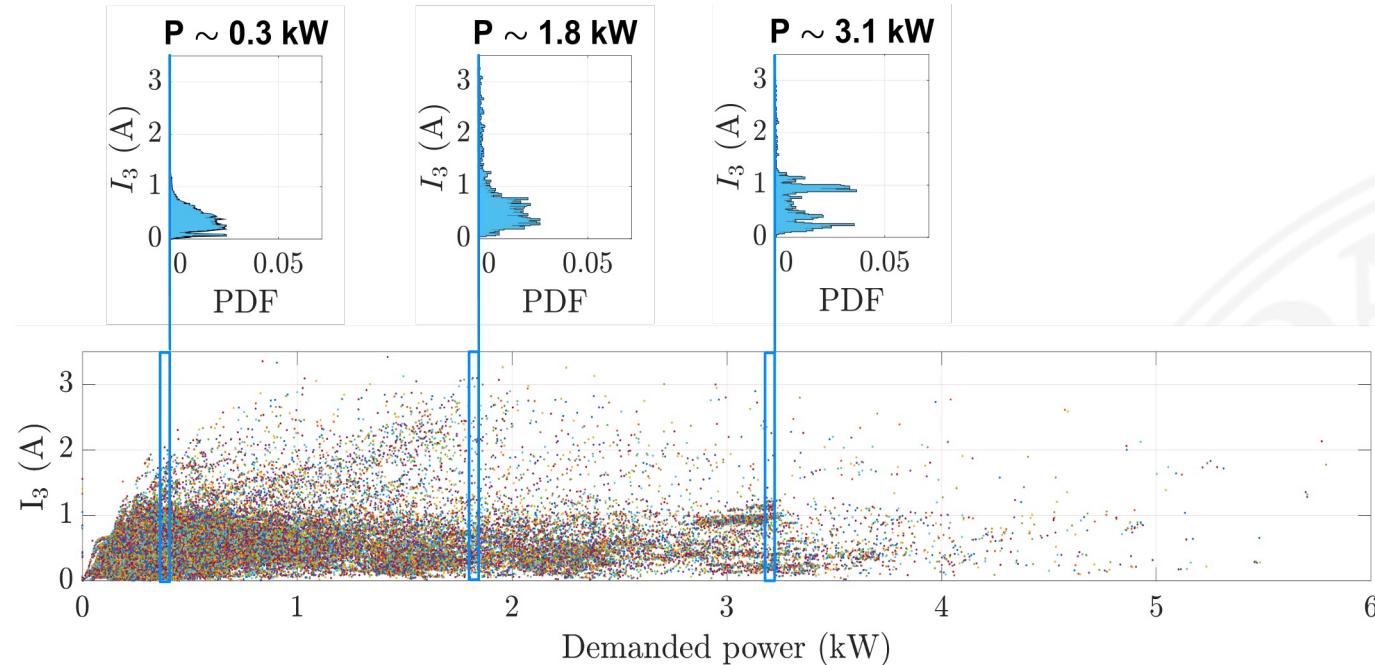


## Measurement campaign

- Harmonic currents from 24 individual residences
- Odd harmonic orders (up to 25th), power and fundamental voltages
- During one week and with one-minute resolution
- Fluke 435 and Fluke 435-II PQ analyzer



# 1. Measurement-based models



Different harmonic magnitude distributions depending on the demanded power

→ Different models for different demanded powers

Distributions do not fit in classical probabilistic distributions

→ Statistical techniques:  
Non-parametric distributions  
Gaussian mixture models

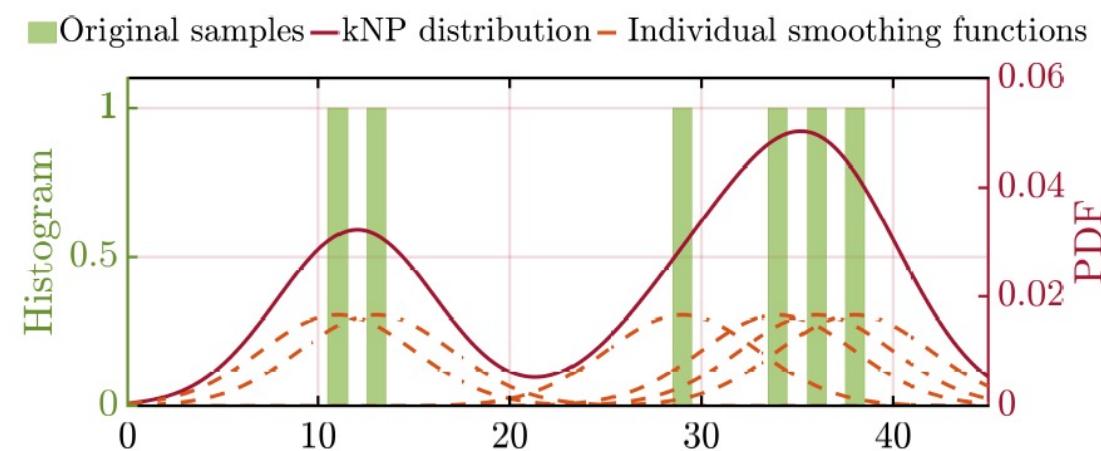


# 1. Measurement-based models

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## A. Non-parametric distributions

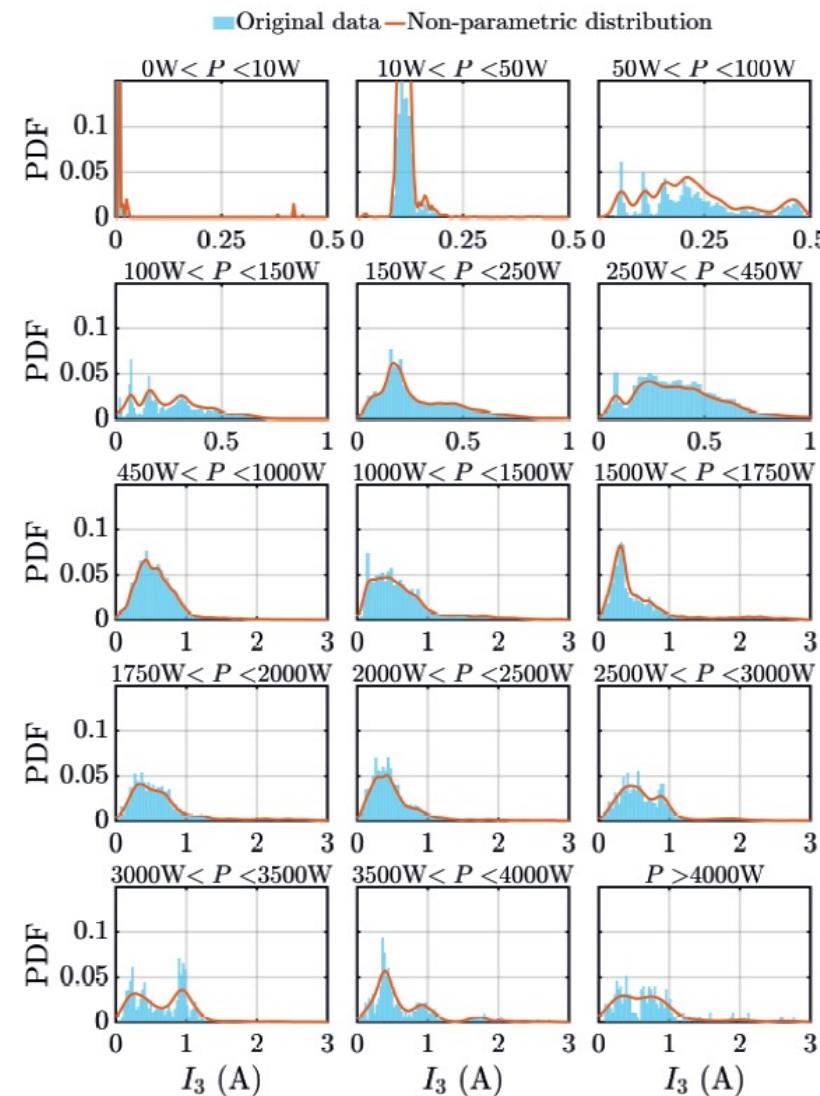
- Kernel non-parametric models for each power interval
- Kernel non-parametric models fit original data into multiple local distributions



# 1. Measurement-based models

## A. Non-parametric distributions

3<sup>rd</sup> harmonic order  
24 residences

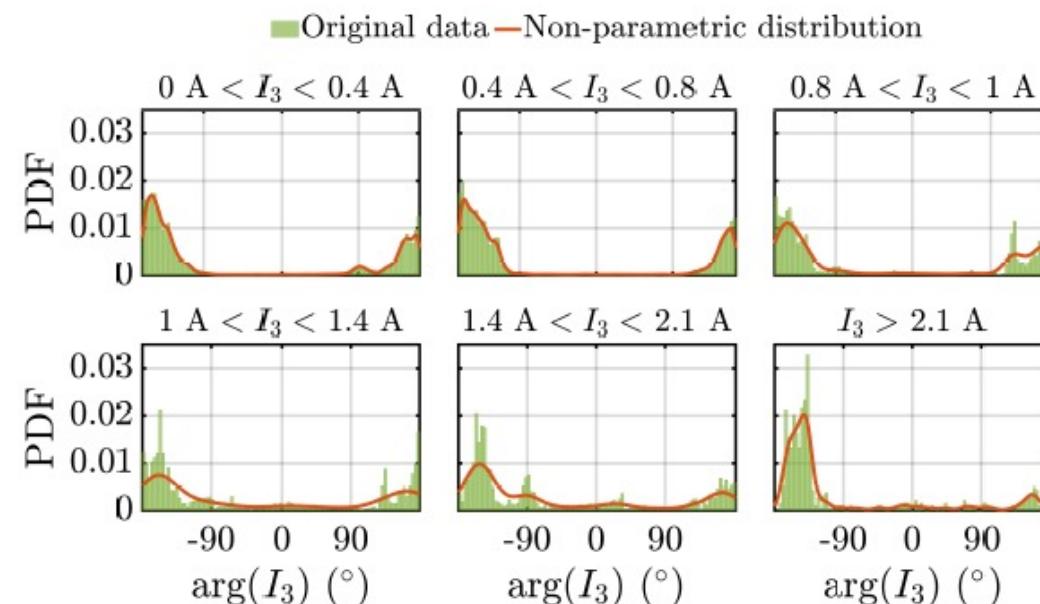


# 1. Measurement-based models

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## A. Distribuciones no paramétricas

3<sup>rd</sup> harmonic order  
24 residences



# 1. Measurement-based models

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## A. Distribuciones no paramétricas

Very Good fitting

Requieres a lot of memory

Sampling of distributions is slow



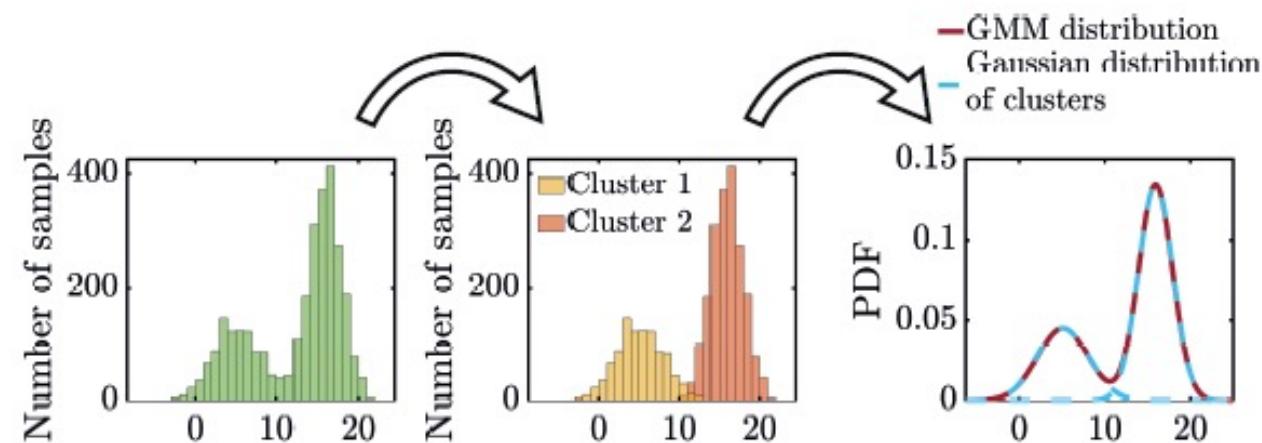
## B. Gaussian Mixtures

# 1. Measurement-based models

## B. Gaussian Mixtures

Multiple weighted Gaussian distributions

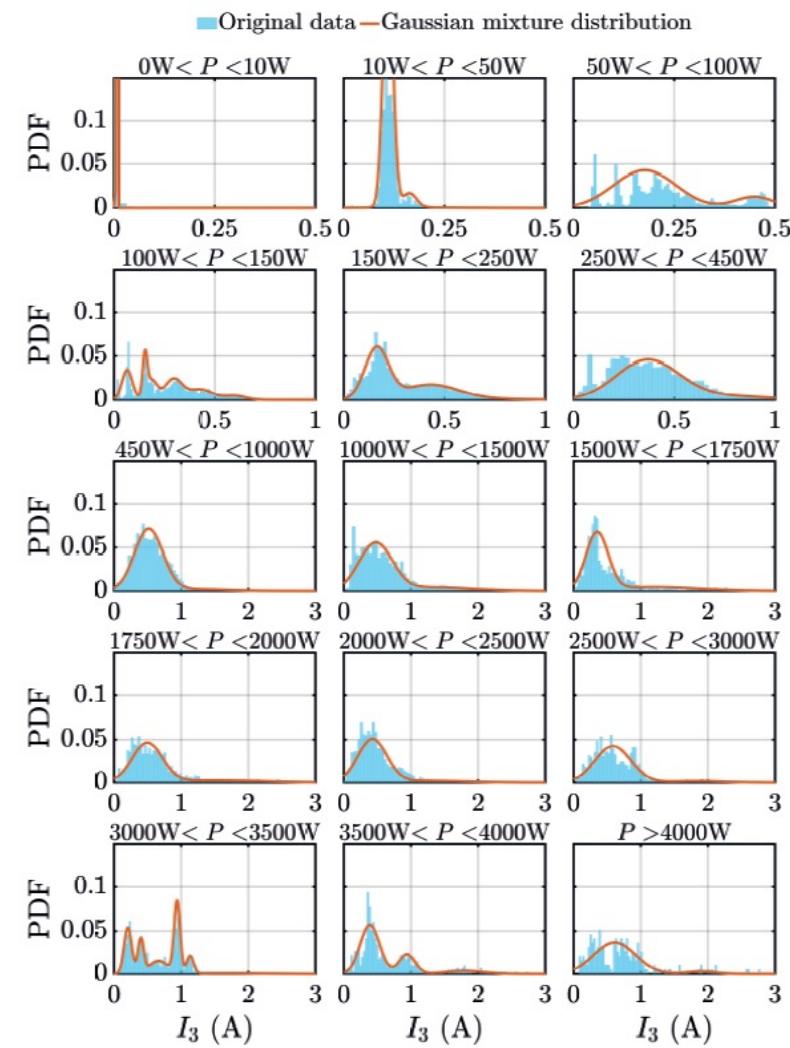
Actual number of distributions decided according to statistical criterion (Sillhouette)



# 1. Measurement-based models

## B. Gaussian Mixtures

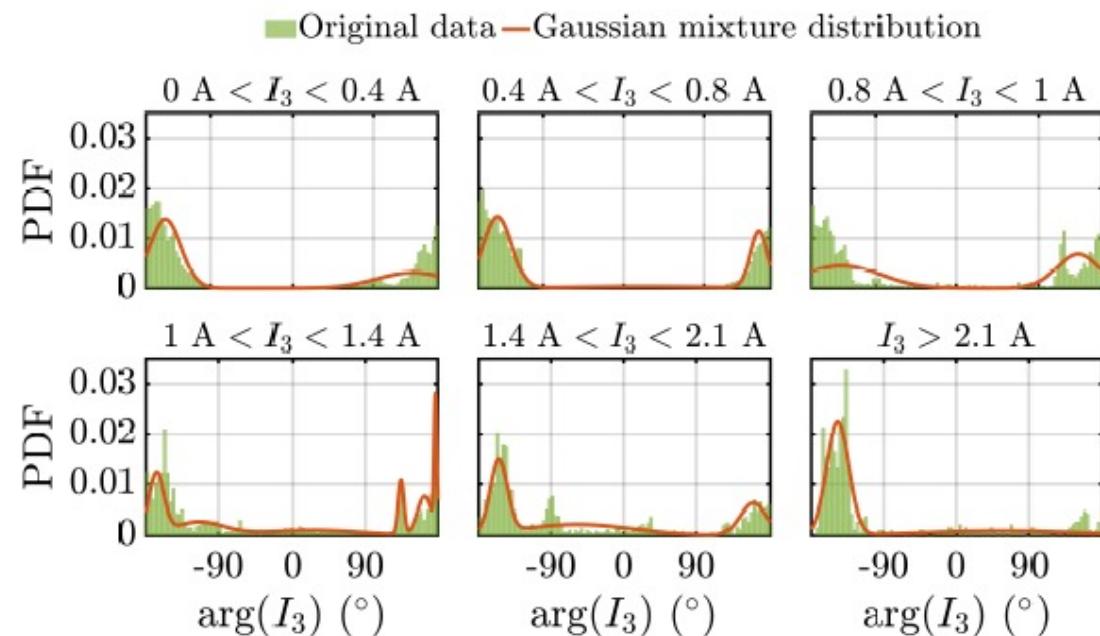
3<sup>rd</sup> harmonic order  
24 residences

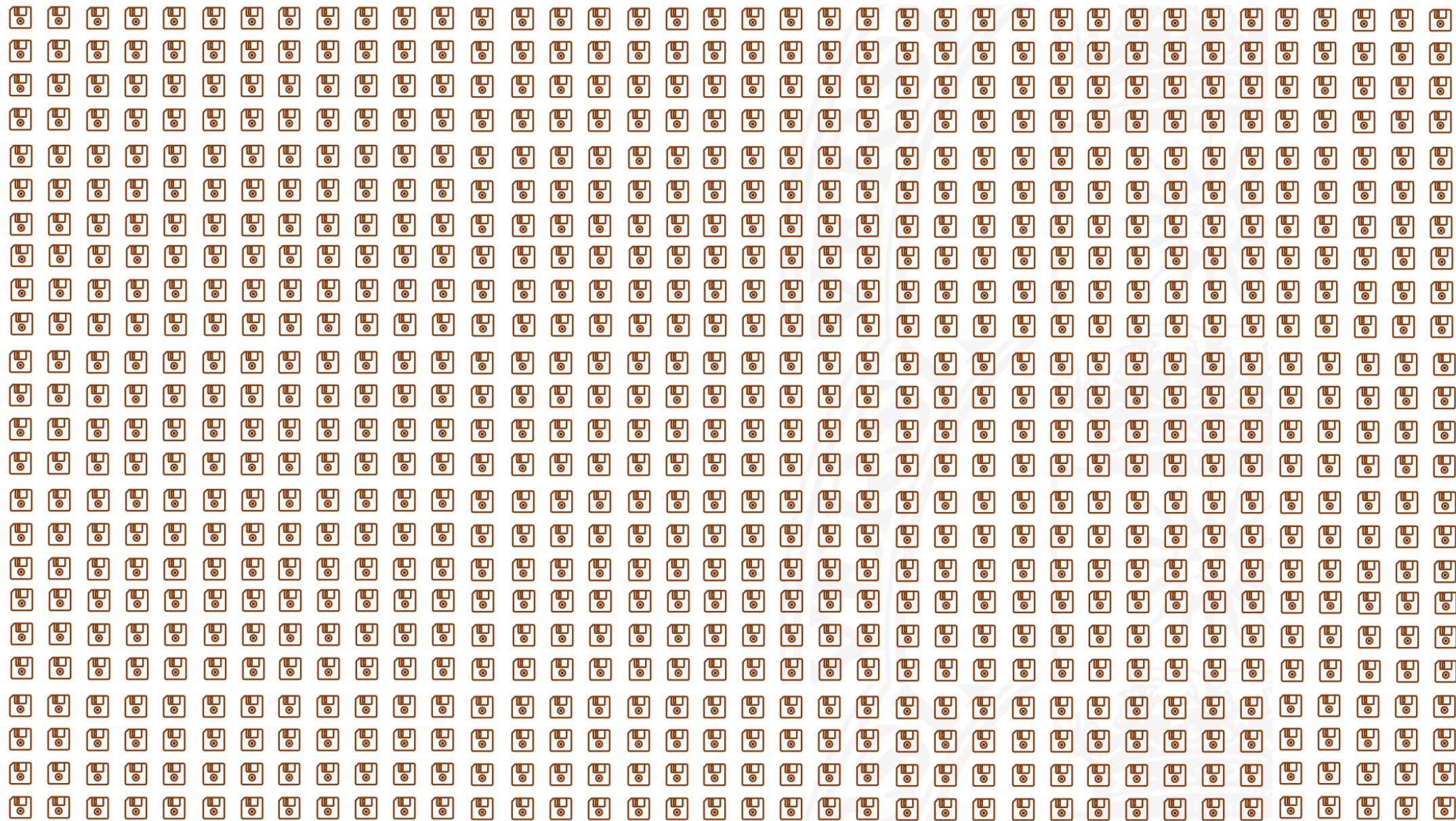


# 1. Measurement-based models

## B. Gaussian Mixtures

3<sup>rd</sup> harmonic order  
24 residences



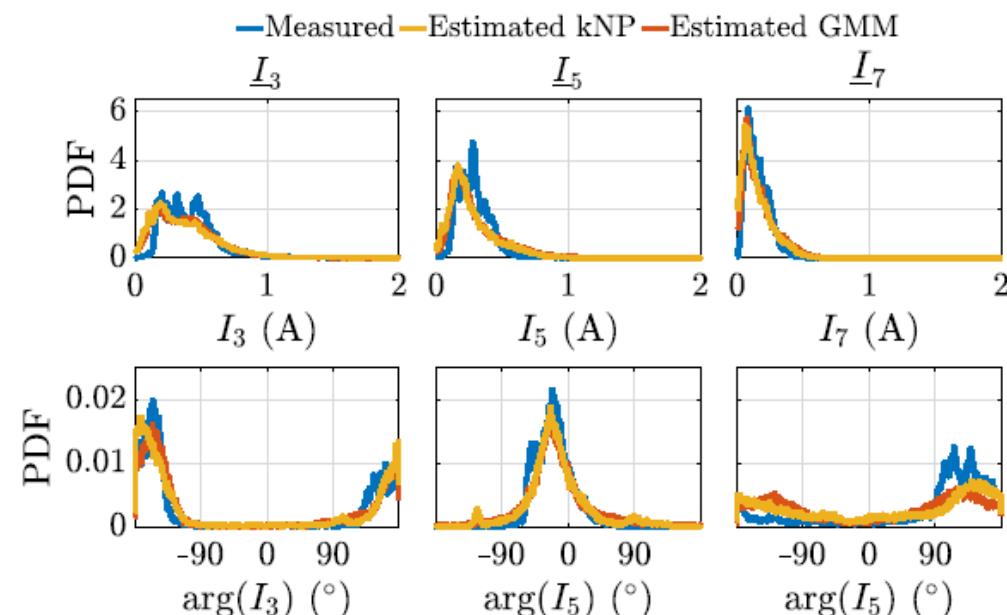


# 1. Measurement-based models

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## Model validation

- 5 different measured residences
- Statistical evidence to conclude they are similar



# 1. Measurement-based models

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Data (MEMORIA)

Rodríguez Pajarón, P. & Hernández Bayo, A.

Measurements of residential injections of harmonics -  
MEMORIA

e-cienciaDatos, 2021

# Contents

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1 Measurement-based models

2 Bottom-up models

## 2. Bottom-up models

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Measurement-based models:

Good fitting of data - same conditions as measured!

Not valid for studying other scenarios



## 2. Bottom-up models

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A  
Probabilistic  
generation of demand  
profiles (device by  
device)



B  
Probabilistic generation  
of harmonic injections



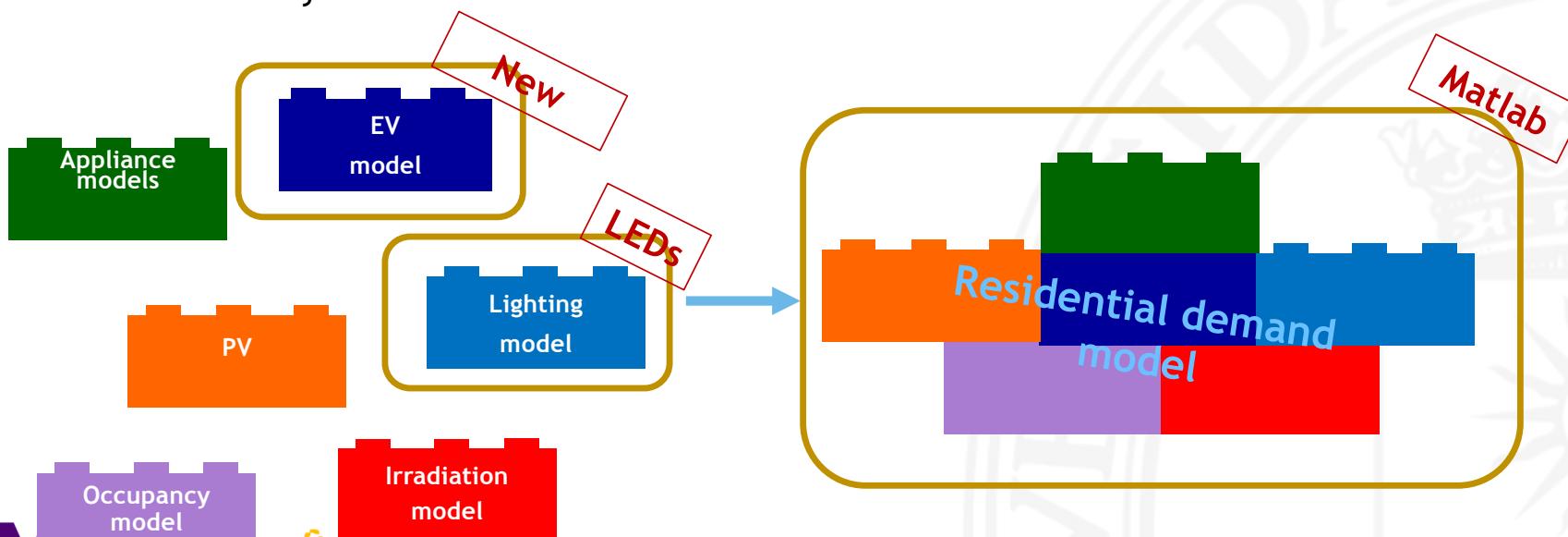
C  
Probabilistic bottom-up  
harmonic injection  
model

## 2. Bottom-up models

### A. Probabilistic generation of demand profiles (device by device)

Based on CREST tool  
Time of use surveys

( Richardson et al. 2010)

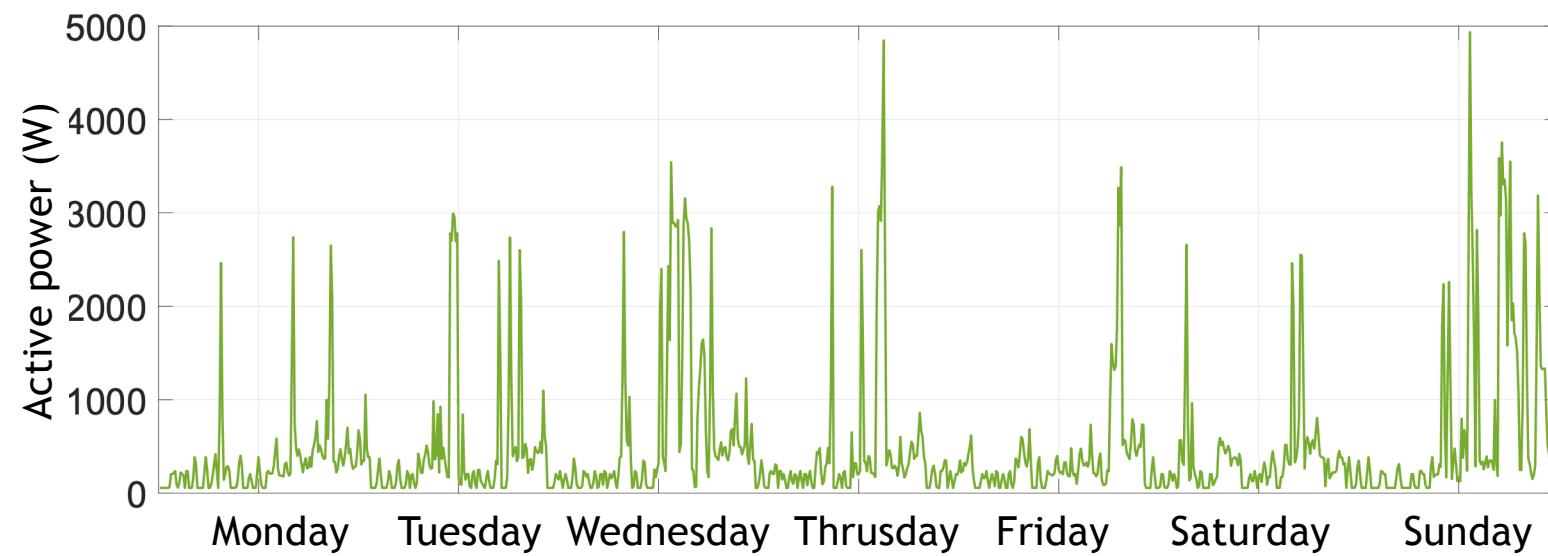


## 2. Bottom-up models

### A. Probabilistic generation of demand profiles (device by device)

Based on CREST tool  
Time of use surveys

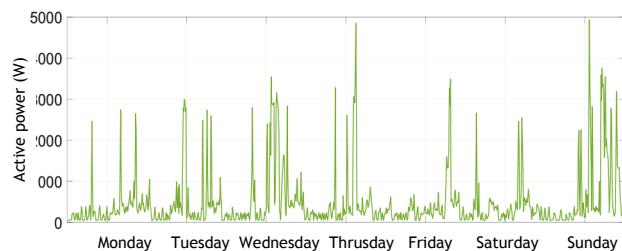
( Richardson et al. 2010)



## 2. Bottom-up models

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A  
Probabilistic generation  
of demand profiles  
(device by device)



B  
Probabilistic generation  
of harmonic injections



C  
Probabilistic bottom-up  
harmonic injection  
model



## 2. Bottom-up models

Each device injects  
Characterized in I

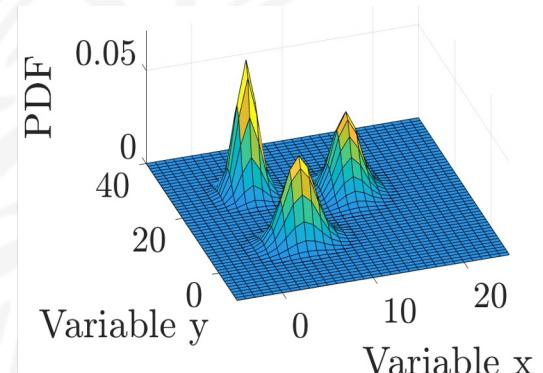
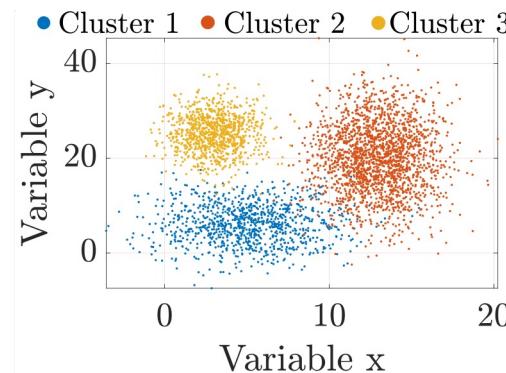
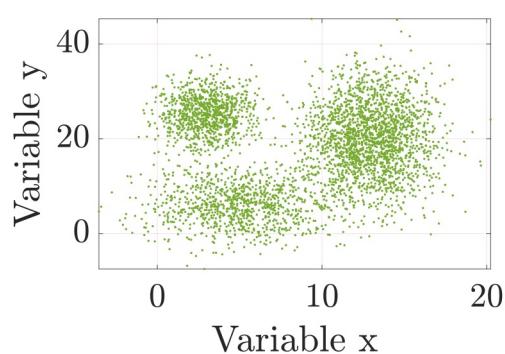
B. Probabilistic generation of harmonic injections

Device	# Samples	Modeling
CFL	1606	Gaussian Mixture
Halogen	14	Random sampling
LEDs	754	Gaussian Mixture
Refrigerator	16	Random sampling
Vacuum	34	Gaussian Mixture
PC	334	Gaussian Mixture
Screen	97	Gaussian Mixture
Laptop	147	Gaussian Mixture
TV	11	Random sampling
TV - flat screen	12	Random sampling
Hob	22	Random sampling
Induction hob	7	Random sampling
Microwave	15	Random sampling
Washing machine	34	Gaussian Mixture
Heat pump	10	Random sampling
PV	15	Random sampling
EV	42	Gaussian Mixture

## 2. Bottom-up models

### B. Probabilistic generation of harmonic injections

Multivariate Gaussian mixture model

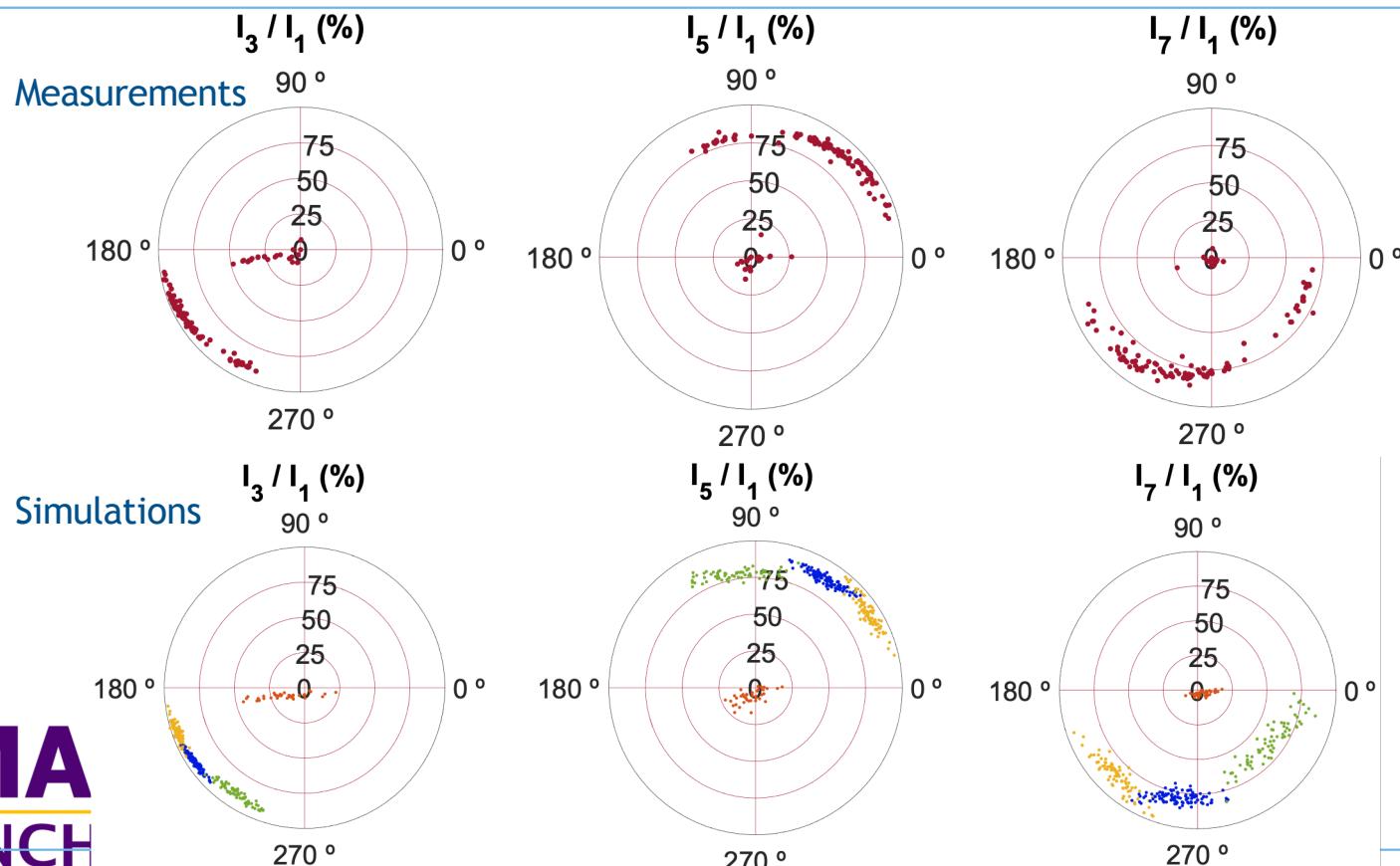


(13 odd harmonic orders from 1 to 25)  $\times$  2 = 26 dimensions



## 2. Bottom-up models

B. Probabilistic generation of harmonic injections

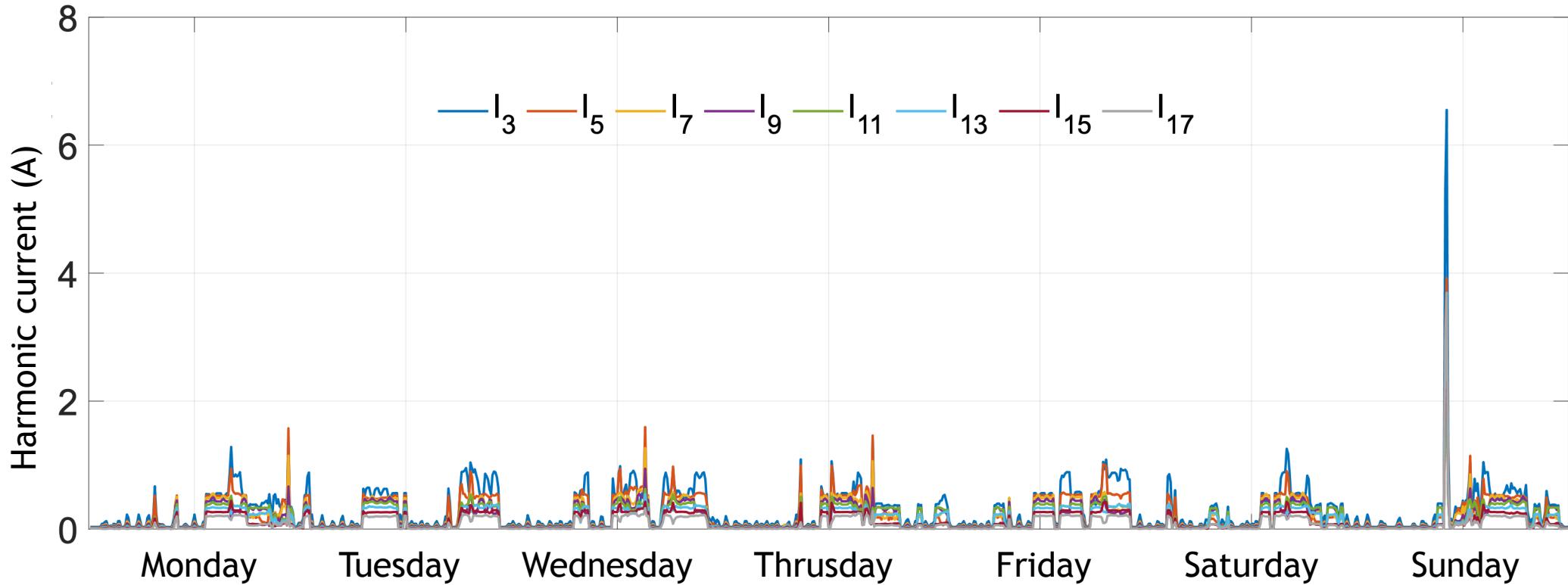


Laptop  
147 samples



**PMA**  
**MANCH**

## 2. Bottom-up models



TV	11	Random sampling
TV - flat screen	12	Random sampling
Hob	22	Random sampling
Induction hob	7	Random sampling
Microwave	15	Random sampling
Washing machine	34	Gaussian Mixture
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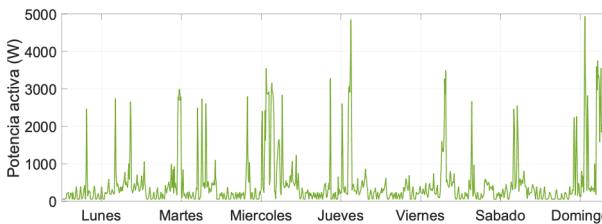
## 2. Bottom-up models

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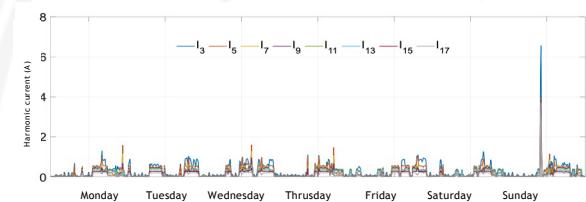
**A.**  
Probabilistic generation  
of demand profiles  
(device by device)



**B.**  
Probabilistic generation  
of harmonic injections

Device	# Samples	Modeling
CFL	1606	Gaussian Mixture
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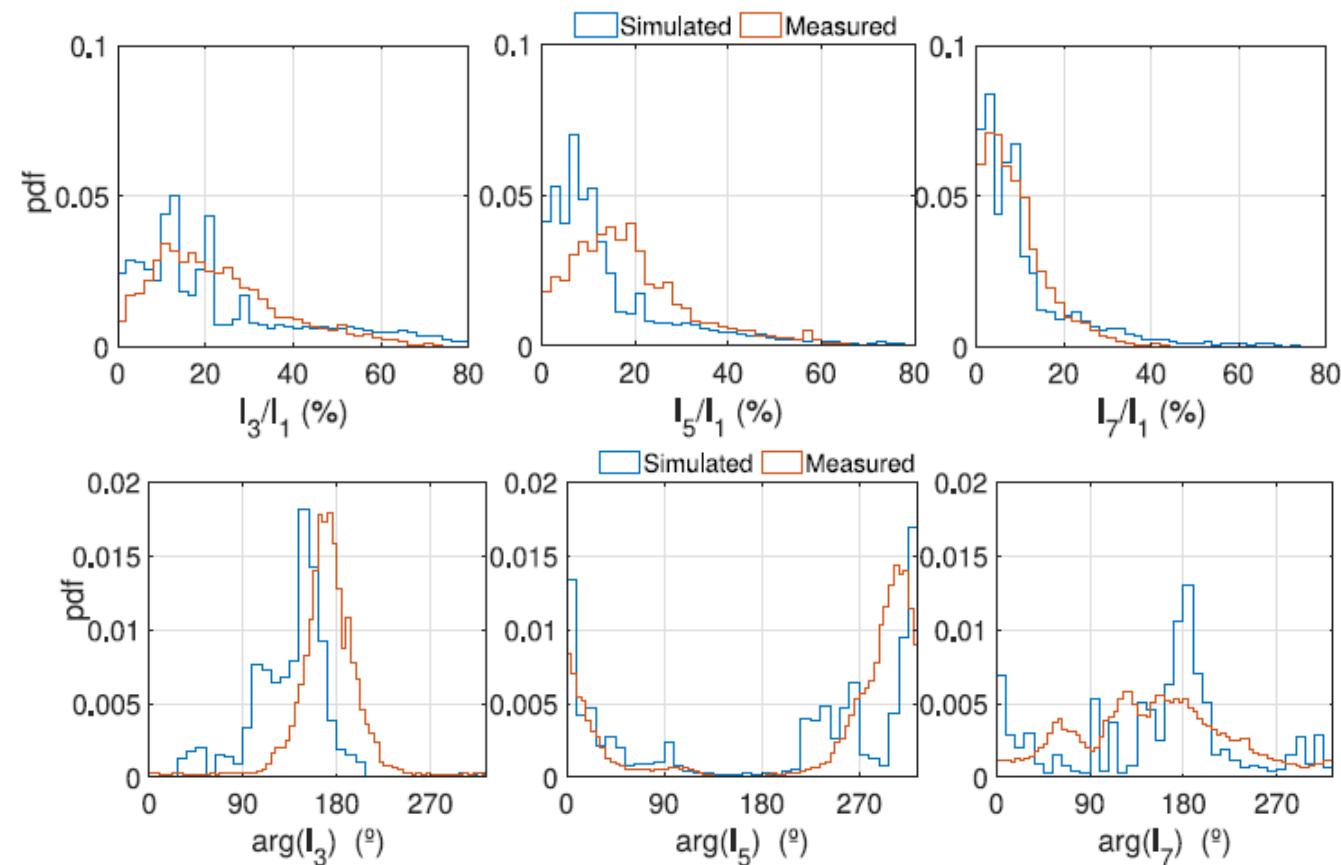
**C.**  
Probabilistic bottom-up  
harmonic injection  
model



## 2. Bottom-up models

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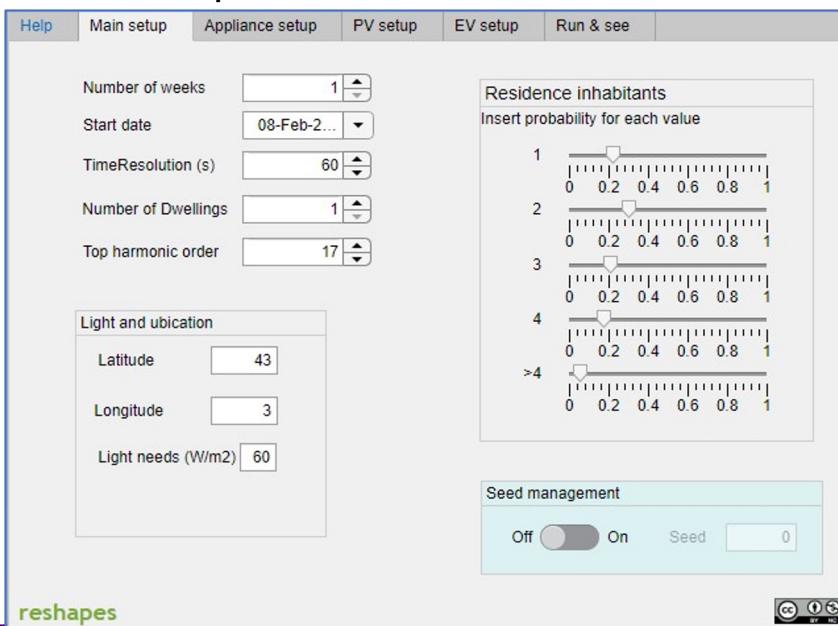
### C. Probabilistic bottom-up harmonic injection model : Validation



## 2. Bottom-up models

### C. Probabilistic bottom-up harmonic injection model

Matlab script and executable tool



The screenshot shows the 'Appliance setup' tab of a Matlab interface. It displays a table of data for various household appliances:

	Penetration (0 to 1)	Mean power (W)		Penetration (0 to 1)	Mean power (W)		Penetration (0 to 1)	Mean power (W)
Chest freezer	0.163	190	TV 1	0.977	124	EWH*	0.01	3000
Fridge-freezer	0.651	190	TV 2	0.58	124	DESWH**	0.17	3000
Fridge	0.43	110	TV 3	0.18	124	Electric shower	0.1	9000
Upright freezer	0.291	155	DVD	0.896	33.55	Storage heater	0	1.02e+
Answer machine	0	0.9	TV reciever	0.934	26.82	Electric heating	0.026	2000
CD player	0.9	15	Hob	0.463	2400			
Clock	0.9	0.05	Oven	0.616	2125	* Electric water Heating		
Phone	0.9	0.05	Microwave	0.859	1250	** Domestic electric storage water heater		
HiFi	0.9	100	Kettle	0.975	2000			
Iron	0.9	1000	Small cooking	1	1000			
Vacuum	0.937	2000	Dish washer	0.335	1131			
Fax	0.2	37	Tumble dryer	0.569	2500			
PC	0.708	140.7	Washing machine	0.934	405.5			
Printer	0.665	335.2	Washer-dryer	0	792			
			Heat pump proportion	0.5				
			VSD washin mchine proportion	0		Laptop proportion of PCs	0.9	
			Induction hob proportion	0.4		Flatscreen TV proportion	0.1	



## 2. Bottom-up models



Data (RESHAPES)

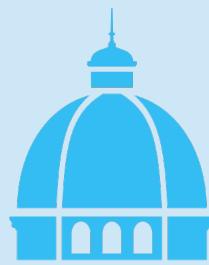
Rodríguez Pajarón, P. & Hernández Bayo, A.

Residential Harmonic Probabilistic Emission Simulator-  
RESHAPES

e-cienciaDatos, 2021



Pablo Rodríguez-Pajarón, Eduardo Caro, Araceli Hernández, Mohamed Izzeddine,  
A Bottom-up model for simulating residential harmonic injections,  
Energy and Buildings, Volume 265, 2022, 112103, ISSN 0378-7788,  
<https://doi.org/10.1016/j.enbuild.2022.112103>.  
(<https://www.sciencedirect.com/science/article/pii/S0378778822002742>)



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**MANCH<sup>EST</sup><sub>1824</sub>ER 2022**



# Thank you!!

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DE CIENCIA  
E INNOVACIÓN



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