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DEPARTAMENT D'ENGINYERIA ELÈCTRICA



Departament d'Enginyeria Elèctrica



UNIVERSITAT POLITÈCNICA DE CATALUNYA



CITCEA - Centre d'Innovació Tecnològica  
en Convertidors Estàtics i Accionaments

**Doctoral Thesis**

# **Aggregated flexibility services for distribution network operation**

**Íngrid Munné Collado**

Thesis advisors:

Dra. Monica Aragues Penalba (UPC, Spain)

Dr. Andreas Sumper (UPC, Spain)

Examination Committee:

Prof. XXXXXXXX (XXXXXX)

Prof. XXXXXXXX (UPC, Spain)

Prof. XXXXXXXX (XXXXXX)

Thesis reviewers:

Prof. XXXXXX (XXXXXX)

Prof. XXXXXXXX (XXXXXX)

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Universitat Politècnica de Catalunya  
Departament d'Enginyeria Elèctrica  
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments  
Av. Diagonal, 647. Pl. 2  
08028, Barcelona

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*"Oh, how much is left to learn"*

*Ziggy Alberts*



*To Silvia,  
Joan and Jèssica.*



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- Danish Technical University (DTU), Denmark.



## **Abstract**

### **Storytelling PhD**

- What is the current situation?
  - Energy Transition - Clean Energy Package
  - Increase on electricity consumption
  - decommissioning of nuclear power plants
  - Importance on society awareness on sustainability, as well as prices in some countries for access to electricity - What is our current carbon footprint?
- What are the problems that we identify?
  - some of the solutions for the energy transition can lead to congestion in distribution networks, due to the placement of DERs in MV and LV networks.
  - Are we sure that DERs are completely sustainable? Are we really sure that smart grids are completely sustainable, in each and every country?
- Possible solutions
  - Enhance the development of carbon-free technologies by implementing sustainable solutions - Assessment of the environmental impact of electricity production by means of LCA to help in the development of energy policies and planning, as well as including LCA in end-user optimization for achieving lower carbon footprints.
  - Deployment of demand-side flexibility services by means of end-users flexible assets.
- Thesis contributions
  - Assessment tool for evaluating the environmental impact of electricity markets using hourly LCA, by means of Life Cycle Assessment
  - Definition of Flexibility: Characterization, modeling, implementation and evaluation

- Possible use cases of demand-side flexibility: Flexibility services for DSOs.

## Resum



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# Chapter 1

## Introduction

Explicar el problema al qual ens estem adreçant

### 1.1 Smart grids

#### 1.1.1 Distributed Energy Resources

### 1.2 Distribution networks: challenges

### 1.3 Electricity markets

incloure aquí capítol del llibre de local and micro power markets? Power market fundamentals

### 1.4 Regulation framework and new agents in the energy transition

entregable que vam fer amb el pau Plana TFG

#### 1.4.1 Local electricity markets

incloure aquí capítol del llibre de local and micro power markets? Power market fundamentals

### 1.5 Sustainability of smart grids and DERs

Explicació sobre que entenem per sostenibilitat. Quina relació hi ha entre sostenibilitat i smart grids local markets

## **1.6 Objectives and scope**

## **1.7 Thesis related work and activities**

## **1.8 Thesis outline**



# **Chapter 2**

## **The Potential Role of Flexibility for Sustainable Energy Transition**

### **2.1 Environmental Assessment of Smart Grids**

### **2.2 LCA Applied on Electricity Production**

#### **2.2.1 Peak-Hourly Life Cycle Assessment (PH-LCA) Methodology**

#### **2.2.2 Goal and Scope**

#### **2.2.3 Life Cycle Inventory**

#### **2.2.4 Life Cycle Impact Assessment**

### **2.3 Case Study: INVADE H2020 project Pilot-Sites Electricity Grid Mixes**

### **2.4 Discussion**

### **2.5 Conclusion**



# **Chapter 3**

## **Flexibility Services**

### **3.1 The importance of flexibility**

### **3.2 Regulatory framework for flexibility provision**

#### **3.2.1 Flexibility definition**

incloure aqui la definicio que vam treballar amb el pau Plana de segons qui vol la flex com es la definicio

#### **3.2.2 Local Flexibility Markets**

### **3.3 Flexibility definition**

incloure aqui la idea de diferents definicions de flexibilitat

#### **3.3.1 market oriented**

#### **3.3.2 System oriented**

### **3.4 Mathematical formulation for flexibility definition**

incloure aqui idea review hussain sobre flexibility review

### **3.5 Discussion**

### **3.6 Conclusion**



# Chapter 4

## Aggregated Flexibility Forecast

### 4.1 Introduction

RESEARCH QUESTION: Feina que estic fent a DTU

#### 4.1.1 Use cases/Business models for flexibility services and flexibility forecast

#### 4.1.2 Literature review on flexibility forecast

#### 4.1.3 Contribution

- non-intrusive approach
- less data required (15 kHz for NILM algorithms). Here we can work with 1 minute data
- no submetering (only main smart meter data)
- total aggregated load forecast
- from the total load forecast, we forecast the flexibility UP and flex DOWN, as well as the INFLEXIBLE load
- flexible capacity band (power band) forecast

### 4.2 Algorithms proposed

- Hidden Markov Model
- combinatorial optimization
- Factorial hidden markov model?

## **4.3 Methodology**

### **4.3.1 Datasets**

**Synthetic Data - Load Profile Generator**

**Real Data - Pecan Street Dataport**

## **4.4 Load Categorization and Flexibility definition**

### **4.4.1 Mathematical formulation**

### **4.4.2 Simulation**

## **4.5 Results**

## **4.6 Discussion**

## **4.7 Conclusions**

# Chapter 5

## OPF for Congestion management in MV distribution networks

### 5.1 Introduction

RESEARCH QUESTION: INCLOURE FEINA DEL PAPER DEL CIRED

- NUVVE Congestion management
- pilot estabannell INVADE - BD4OPEM
- altres pilots

#### 5.1.1 Use cases/Business models for congestion management

incloure aqui diagrama interaccio de l INVADE-CIRED Possibilitat d incloure els use cases que estem fent pel BD4OPEM

#### 5.1.2 Standards and protocols for flexibility provision between aggregators and DSOs

OPENADR - USEF?

#### 5.1.3 Literature review on congestion management tools - OPF

#### 5.1.4 Contribution

### 5.2 Mathematical formulation for Flexibility request calculation

- OPF (Python)

## **5.3 Methodology**

### **5.3.1 Datasets - Network Data**

### **5.3.2 Mathematical formulation**

### **5.3.3 Simulation**

## **5.4 Results**

## **5.5 Discussion**

## **5.6 Conclusions**



# **Chapter 6**

## **Conclusions**

### **6.1 General conclusions**

### **6.2 Contributions**

### **6.3 Future work**



# Appendix A

## Publications

### Included in the thesis

#### Published journal papers

- J2** P. Olivella-Rosell, P. Lloret-Gallego, Í. Munné-Collado, R. Villafafila-Robles, A. Sumper, S. Ottesen, J. Rajasekharan, B. Bremdal, “Local flexibility market design for aggregators providing multiple flexibility services at distribution network Level,” *Energies*, vol. 11, no. 4, p. 822, Apr. 2018. doi: 10.3390/en11040822

#### Submitted journal papers

- J4** flexibility review hussain

#### Conference papers

- C1** I. Munné-Collado, P. Lloret-Gallego, P. Olivella-Rosell, R. Villafafila-Robles, S. Ø. Ottesen, R. Gallart-Fernandez, V. Palma-Costa, A. Sumper, “System architecture for managing congestions in distributions grids using flexibility,” 25th International Conference on Electricity Distribution, June 2019.

- conference sara LCA

#### Book chapters

- BC1** Í. Munné-Collado, P. Olivella-Rosell, A. Sumper, “Power Market Fundamentals,” in A. Sumper (ed) *Micro and Local Power Markets*, John Wiley & Sons, pp. 1-35, 2019. doi: 10.1002/9781119434573.ch1
- BC2** Í. Munné-Collado, E. Bullich-Massagué, M. Aragüés-Peñalba, P. Olivella-Rosell “Local and Micro Power Markets,” in A. Sumper (ed) *Micro and*

Local Power Markets, John Wiley & Sons, pp. 37-97, 2019.  
doi: 10.1002/9781119434573.ch2

## Not included in the thesis

### Published journal papers

**J3** Í. Munné-Collado, F. M. Aprà, P. Olivella-Rosell, R. Villafafila-Robles, A. Sumper, “The potential role of flexibility during peak hours on greenhouse gas emissions: a life cycle assessment of five targeted national electricity grid mixes,” *Energies*, vol. 12, no. 23, Nov. 2019. doi: 10.3390/en12234443

**J4** review sara big data

**J5** review hussain

### Submitted journal papers

#### Conference papers

- kejrwejr

## Local conferences

### Published papers

### Conference presentations

## Supervised bachelor and master thesis

**T1** F. Aprà, “Environomical analysis of peak hours electricity production in targeted European countries”, June 2019.

**T2** K.,Beehuspoteea, “Impact factors of heat generation units for zoned temperature controlled in office buildings”, June 2019.

**T3** A. Quattrone, “Development of flexibility device models for a micro-grid laboratory test”, June 2019.

**T4** N. Condorelli, “Evaluation and forecast of CO2 emissions in the electricity sector for European targeted countries” March 2020.

- T5** P. Plana, “Analysis of measures to increment the share of renewable energy in distribution grids” April 2020.
- T6** A. Bové Salat, “Optimal scheduling of flexible assets under a HEMS for prosumers’ economic savings” June 2020.
- T7** M. Ferran, “Power flow tool for active distribution grids and flexibility analysis”, June 2020.

## **Published technical reports**

- TR7** E. F. Bødal, P. Crespo-del-Granado, H. Farahmand, M. Korpås, P. Olivella-Rosell, I. Munné-Collado, P. Lloret-Gallego, “INVADE Deliverable 5.1 Challenges in distribution grid with high penetration of renewables,” June 2017. doi: 10.5281/zenodo.853271
- entregables INVADE LCA?
  - entregables EMPOWER LCA?

