Intelligent Control of EVs: Lessons Learned from the Largest UK EV Trial

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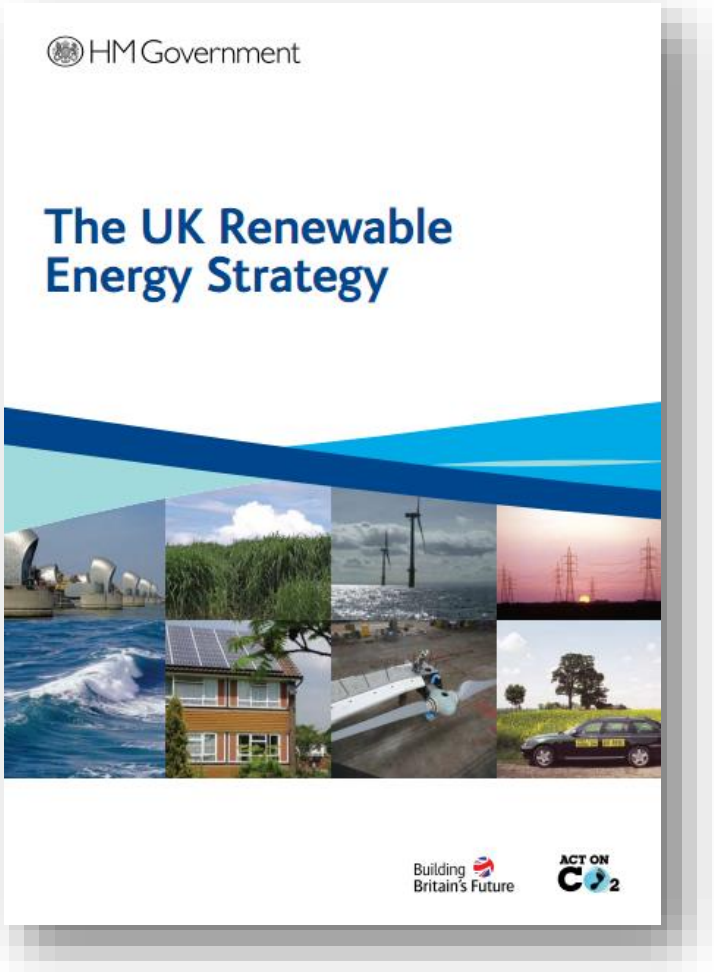
Outline

- The UK Context (for Distribution)
  - Towards a Low-Carbon Society, Some Stats, UK Incentives
- My Electric Avenue (MEA) Project
  - EV Charging Behaviour
  - EV Impact Studies (Business As Usual)
  - EV Management (ESPRIT-Based Control)
    - Field example
    - Economic and carbon assessment
- Conclusions

The UK Context for Distribution

- Business regulated by Ofgem
- Assets account for 50%+ of the value of GB electricity networks
- A significant part of the assets installed during the 1950s and 60s

The UK Context for Distribution



- Legally-binding target of <u>15% of energy demand to be sourced by renewables by 2020</u>
- Expectation by 2020: more than 30% of electricity generated from renewables

Towards a Low-Carbon Society

- Government incentives for renewable generation
- Government incentives for micro/small-scale PV generation
- Government incentives for people to buy electric vehicles (EVs)
- Full smart meter rollout by 2020
- Electrification of heat, advent of smart appliances?

The UK – Some Stats

60 Million

Population

55 GW

Peak Demand (winter)

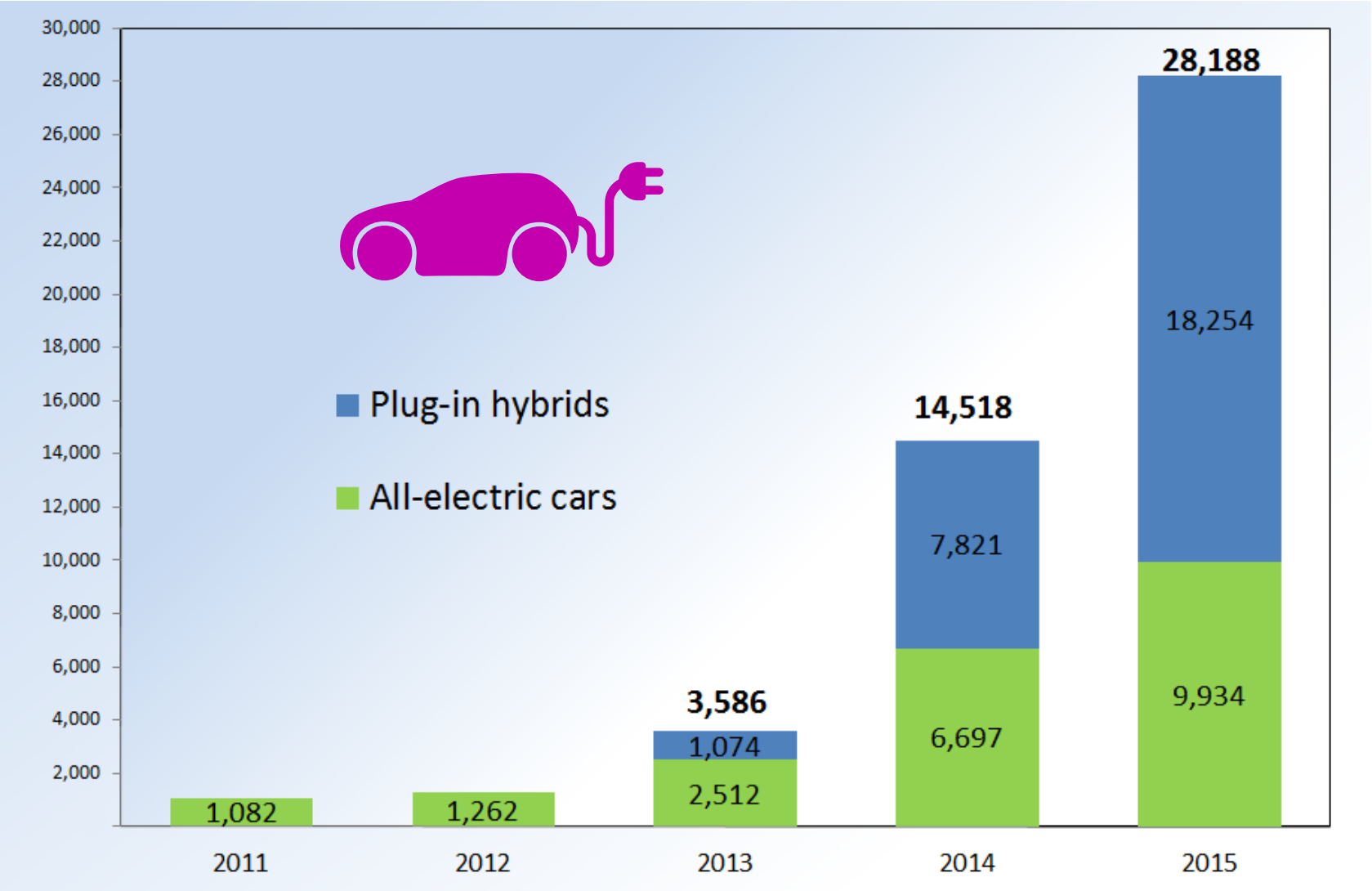
8+ GW

Installed PV capacity

13+ GW

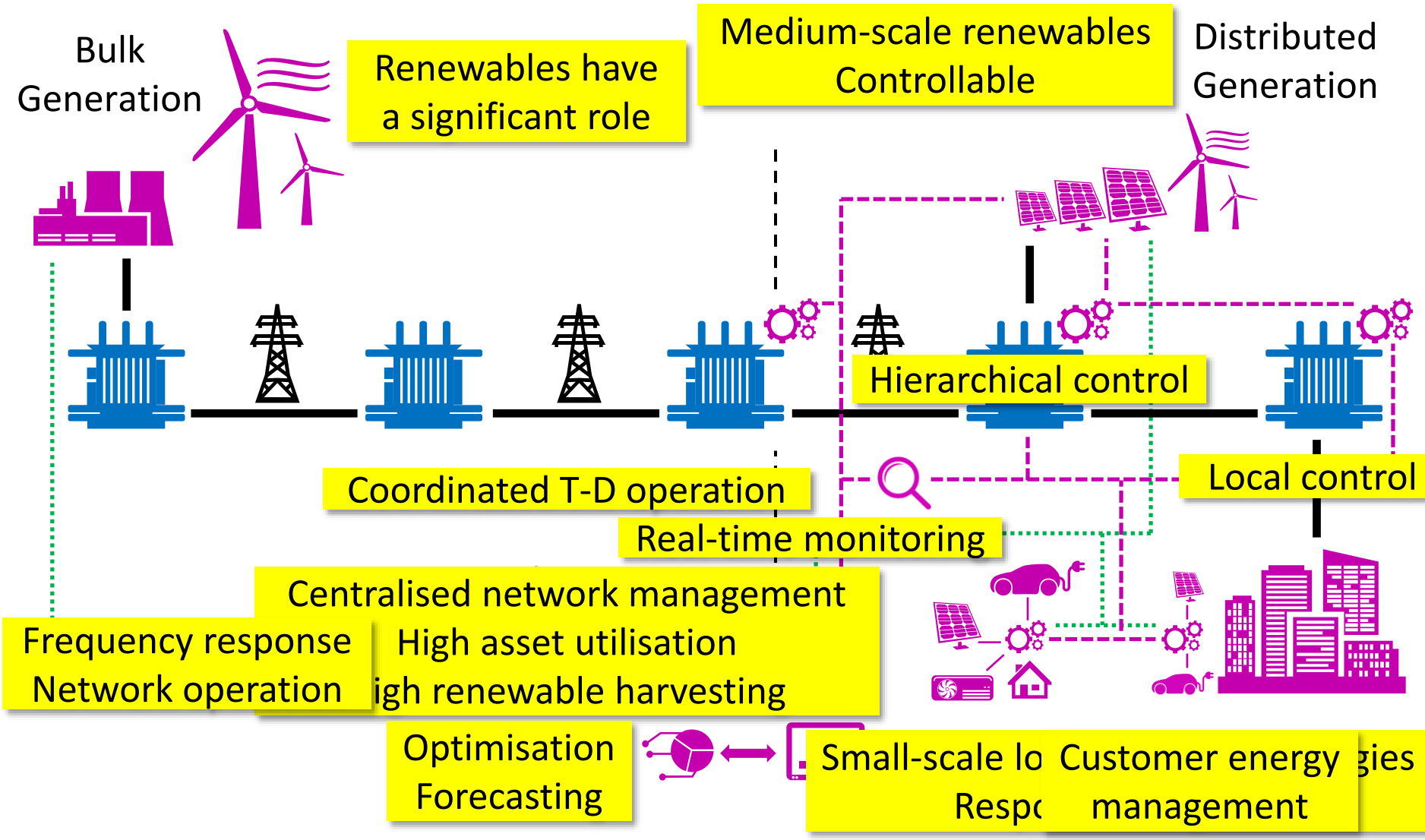
Installed wind capacity

The UK – Some Stats – Plug-in EVs



Source: Mario Roberto Duran Ortiz. https://commons.wikimedia.org/wiki/File:PEV_Registrations_UK_2011_2014.png

Smart & Low Carbon



UK Innovation Incentives

- Regulatory Period **2010-2015: DPCR 5**
  - Low Carbon Networks Fund (LCNF)
  - **US$750m+** for DNOs to **try out new technology, operating and commercial arrangements**
  - Tier 1: direct allocation for small projects
  - Tier 2: competitive for large projects

- Regulatory Period **2015-2023: RIIO-ED1**
  - Tier 1 → Network Innovation Allowance
  - Tier 2 → Network Innovation Competition
  - … similar level of funding

R=I+I+O

Reducing the investment risk of moving towards Smart Grids

My Electric Avenue (MEA)

Total Cost
US$15m

MY ELECTRIC AVENUE

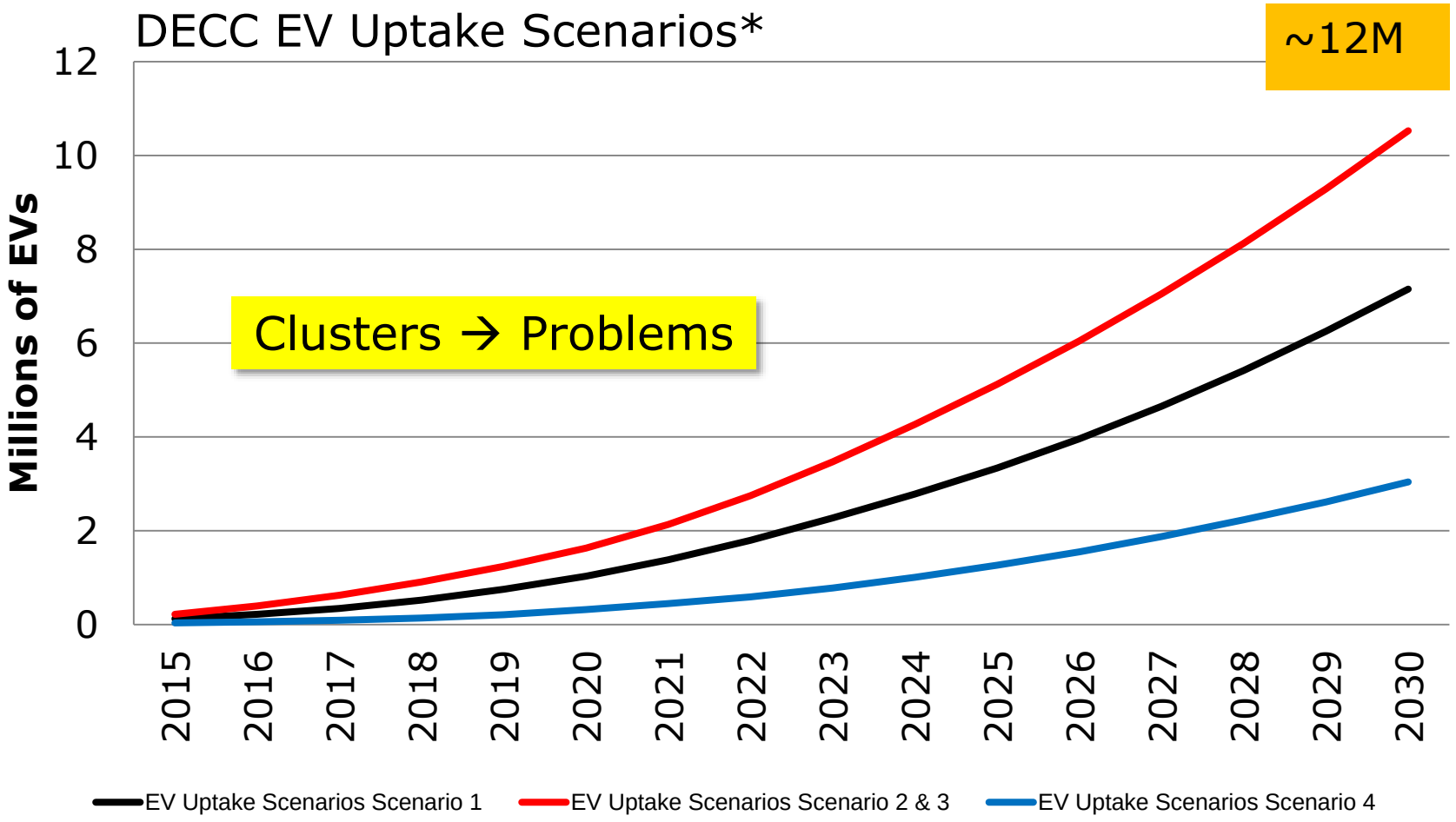
Project run by
EA Technology
Funding DNO
SSE PD

ea technology

Scottish and Southern Energy
Power Distribution

myelectricavenue.info

Electric Vehicles (EVs) in the UK



* Department of Energy and Climate Change (DECC) – https://www.ofgem.gov.uk/ofgem-publications/56824/ws3-ph2-report.pdf

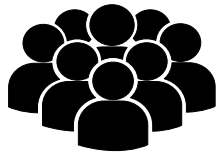
EV Challenges

- EV Clusters
  - Can affect the infrastructure close to customers (LV networks)
  - Thermal overloads, voltage drops

MY ELECTRIC AVENUE

Control of EV Charging Points

- EV Management
  - Cost-effective infrastructure
  - Fair criteria to control EVs
  - Customer acceptance

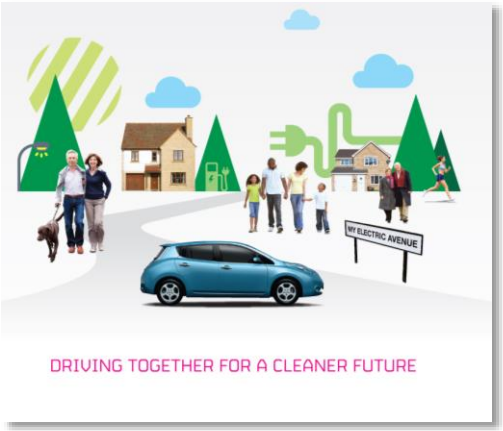


My Electric Avenue (MEA)

Aims:

- To understand charging behaviour of (200+) EV users
- To investigate the impacts of EVs on 9 real LV networks
- To trial a cost-effective and practical solution to control EV charging points (Esprit Technology*)

MY ELECTRIC AVENUE



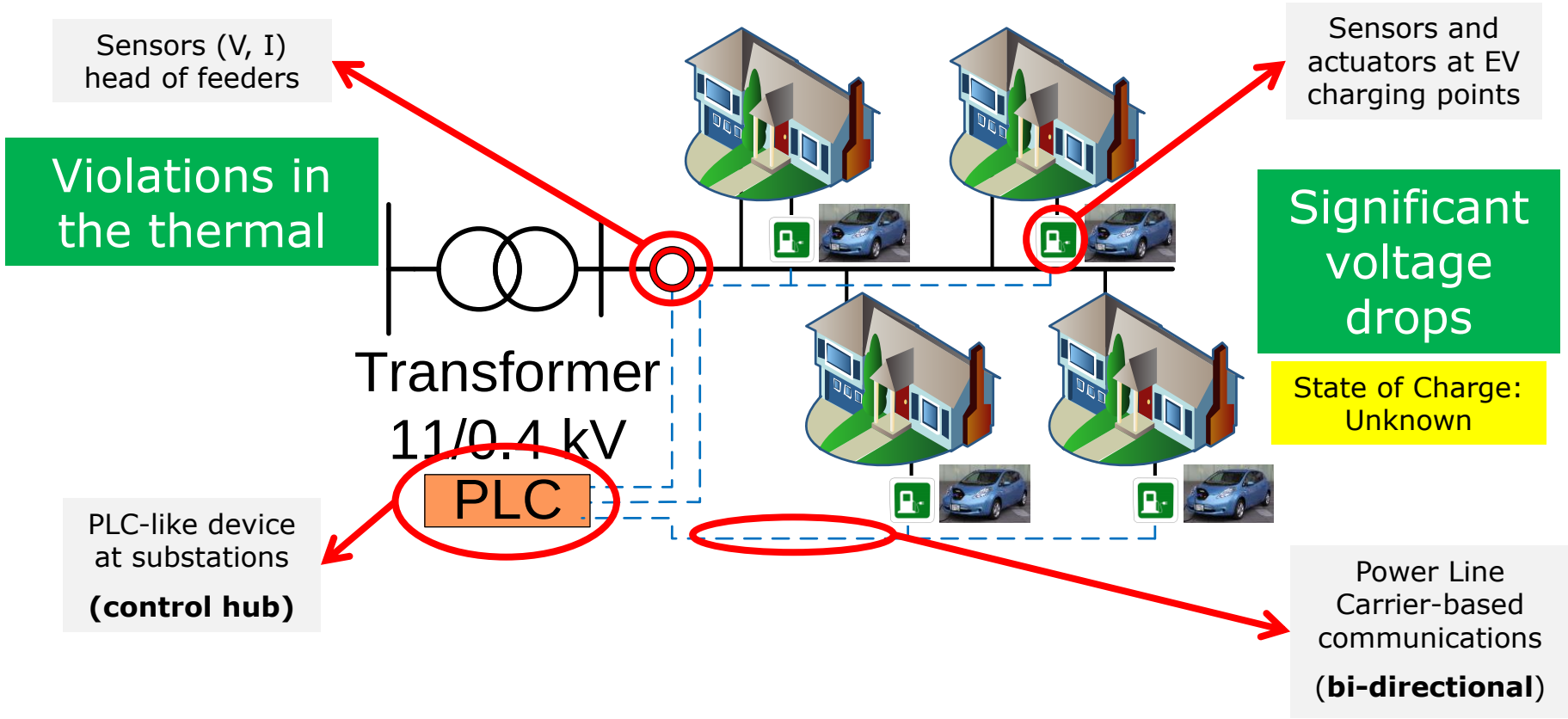
Geographical Extent of the Trial

112 Social Trials

109 Technical Trials

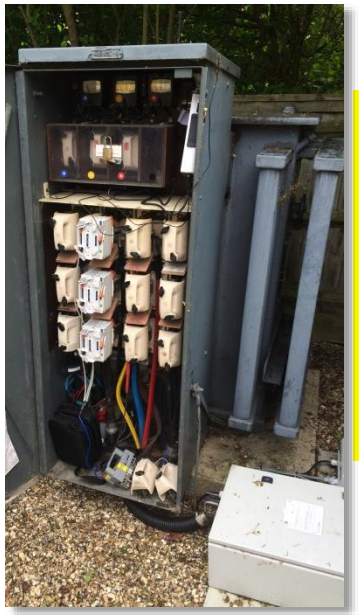
221 in total

Infrastructure Overview

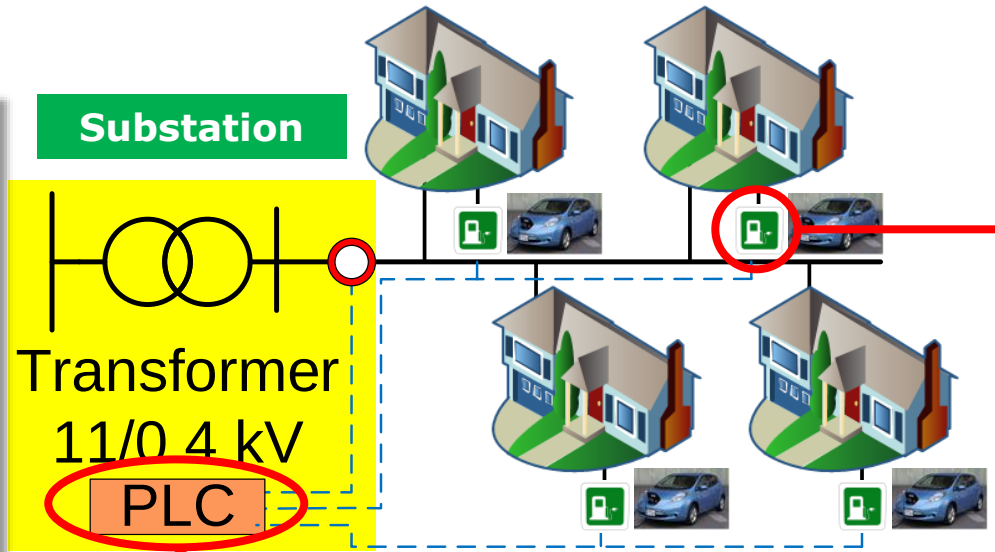


MEA makes the most of available infrastructure

Infrastructure Overview



Real 500 kVA Transformer



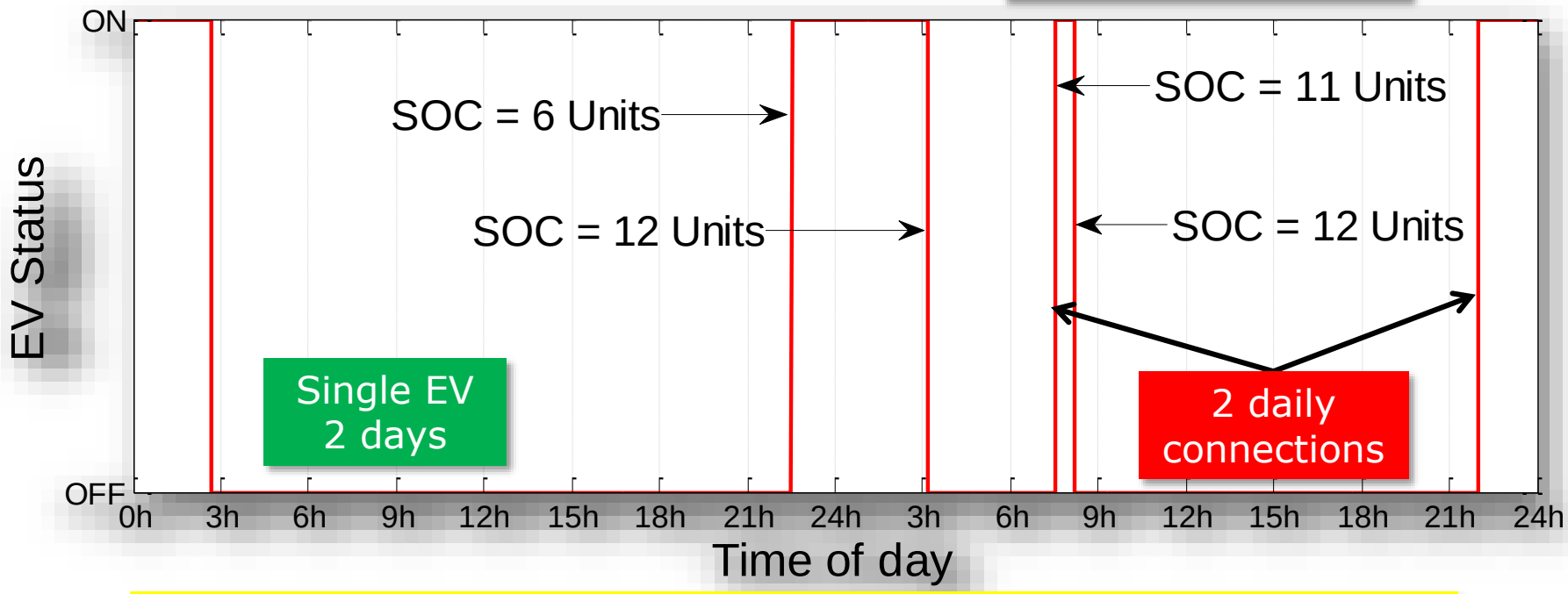
ROLEC* charging point + EA Technology **Intelligent Control Box**

* http://www.rolecserv.com/

EV Charging Behaviour

More than 75,000 charging samples

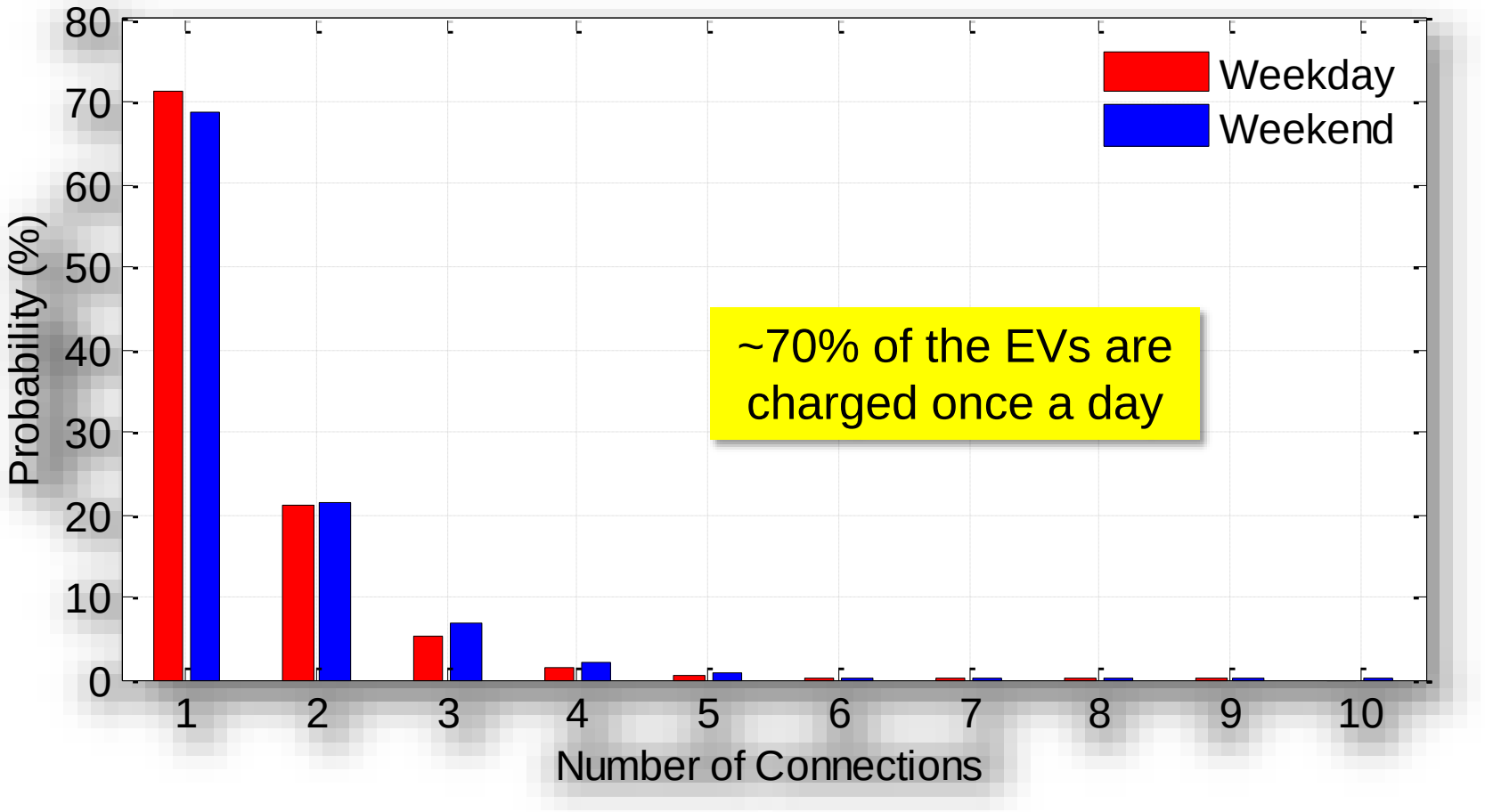
(without control)



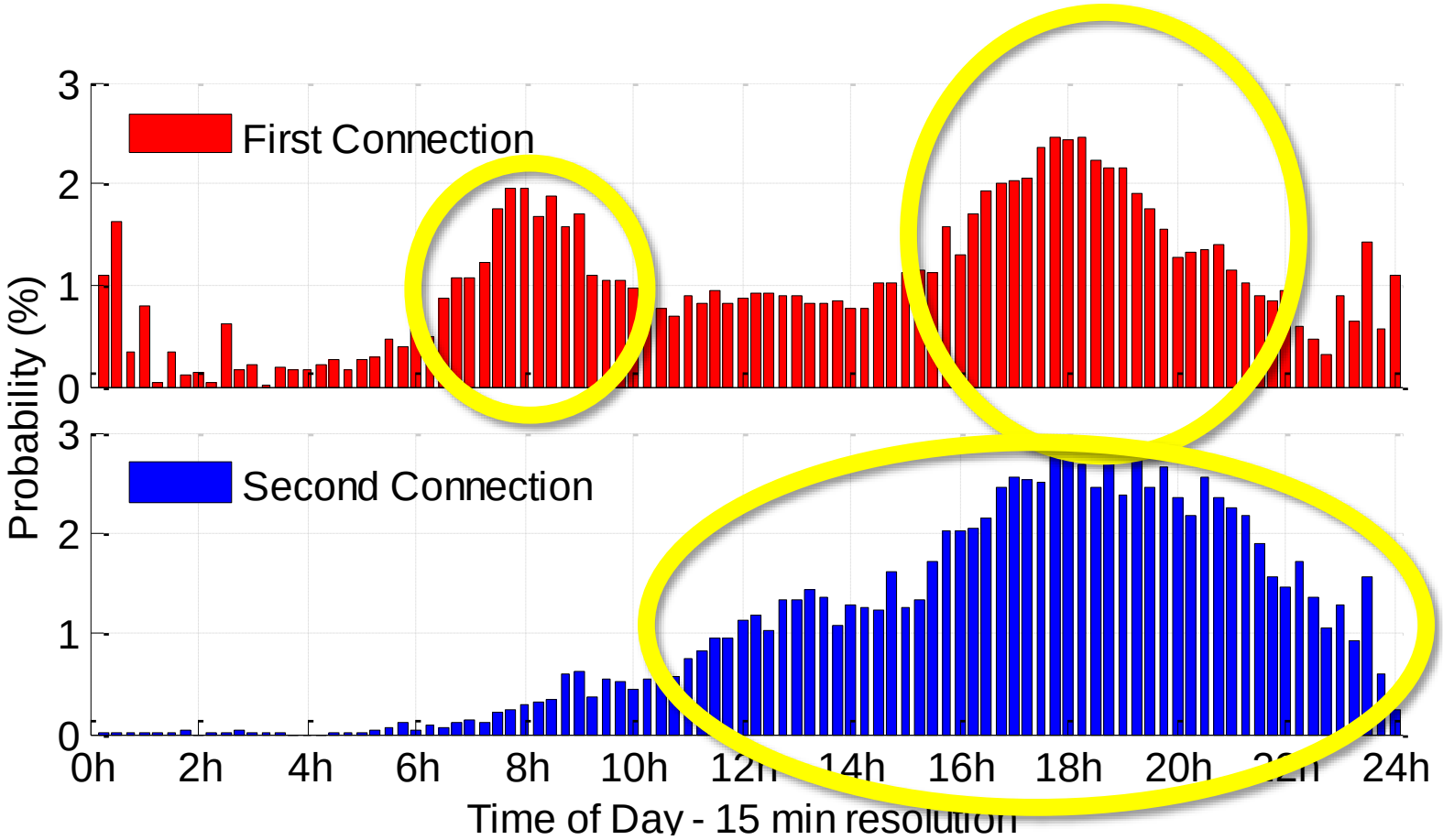
Crucial to understand EV users charging behaviour

*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

Number of Charging Events per Day

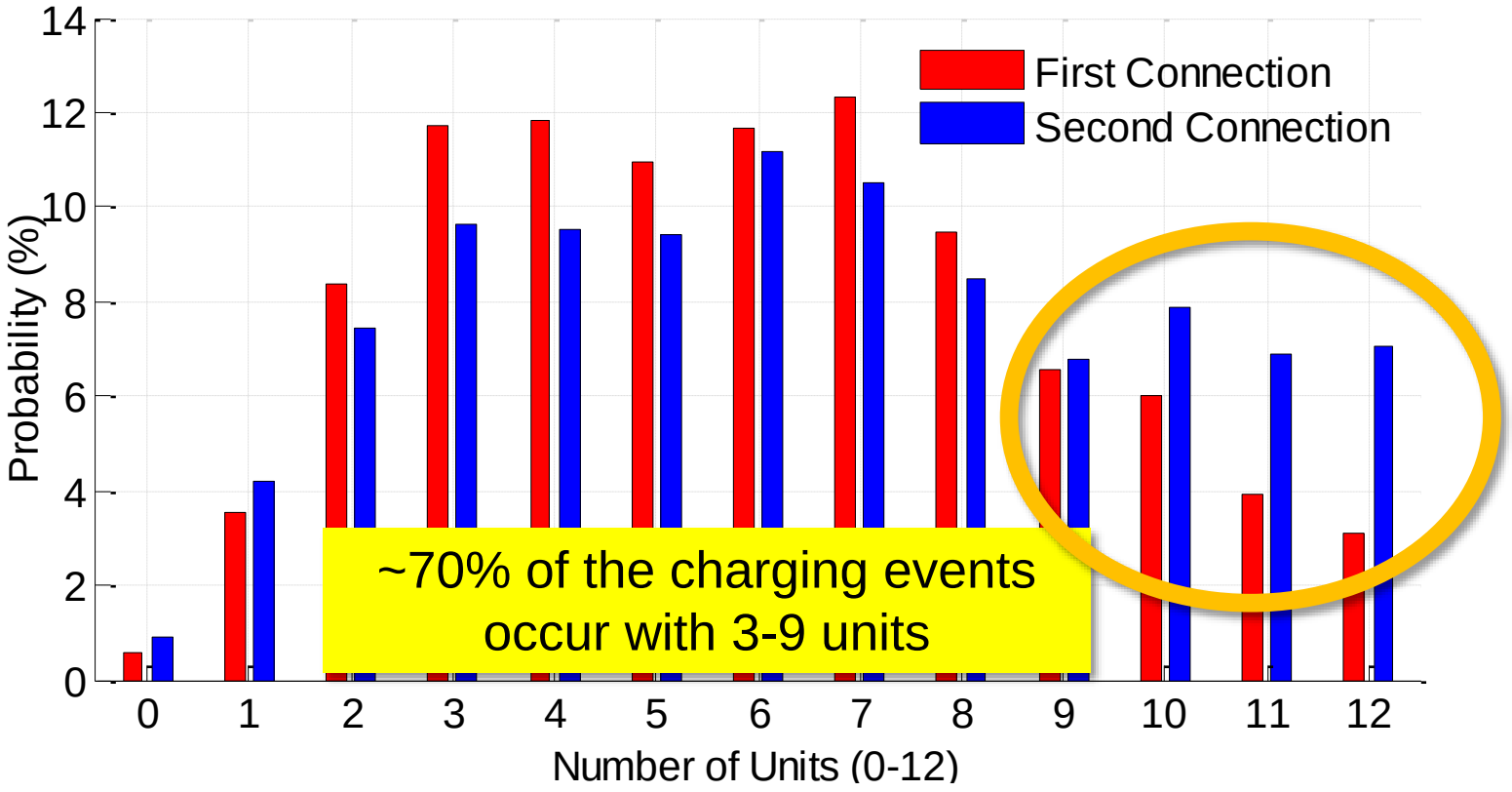


Start Charging Time



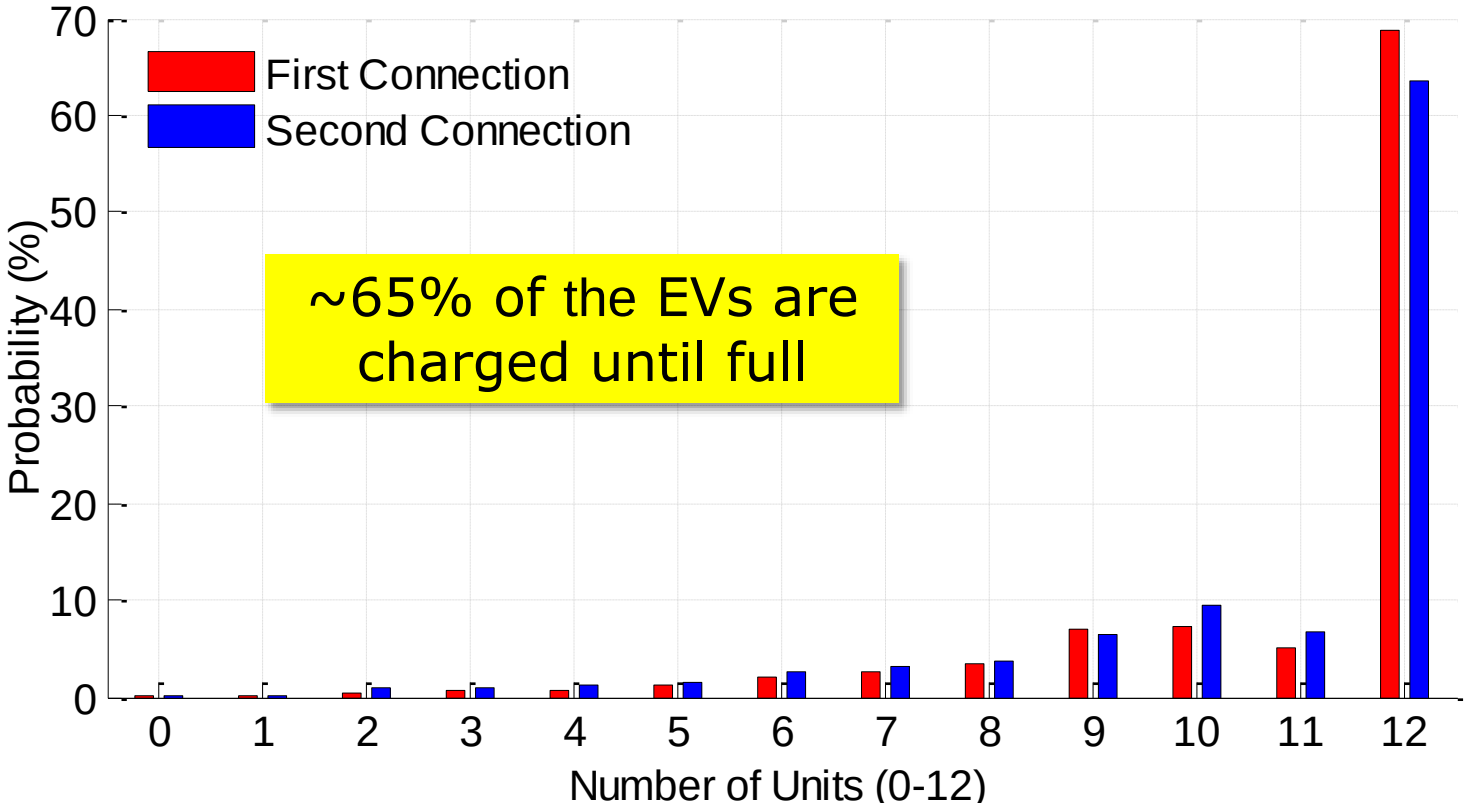
Weekdays

Initial Charging Level



Weekdays

Final Charging Level

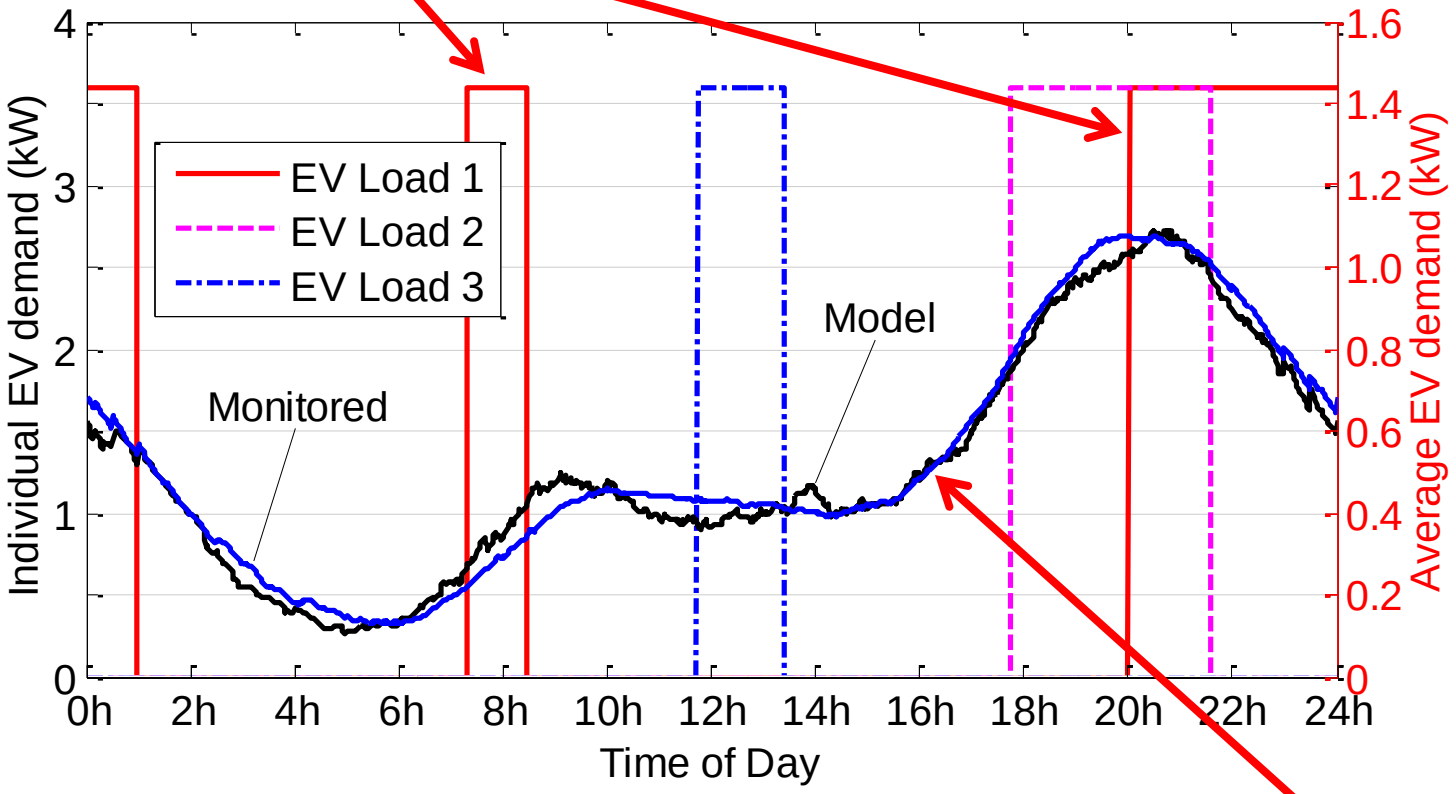


Weekdays

EV Charging Behaviour

Two charging events

EVs can be connected any time



Created models match monitored behaviour

Weekdays

Stochastic Impact Analysis of EVs

- To understand the behaviour and needs of future LV networks with high penetrations of EVs
- Stochastic Analysis (Monte Carlo) to cater for uncertainties
  - EV charging behaviour, load profile, etc.
- Metrics
  - Thermal overloads
  - Voltage issues (BS EN 50160)

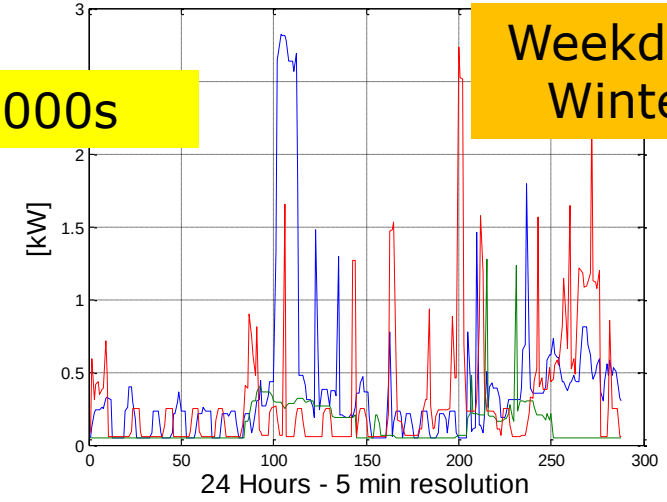
*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

Impact Analysis: Input Data

- Real LV **networks**
- Realistic **domestic** load **profiles***

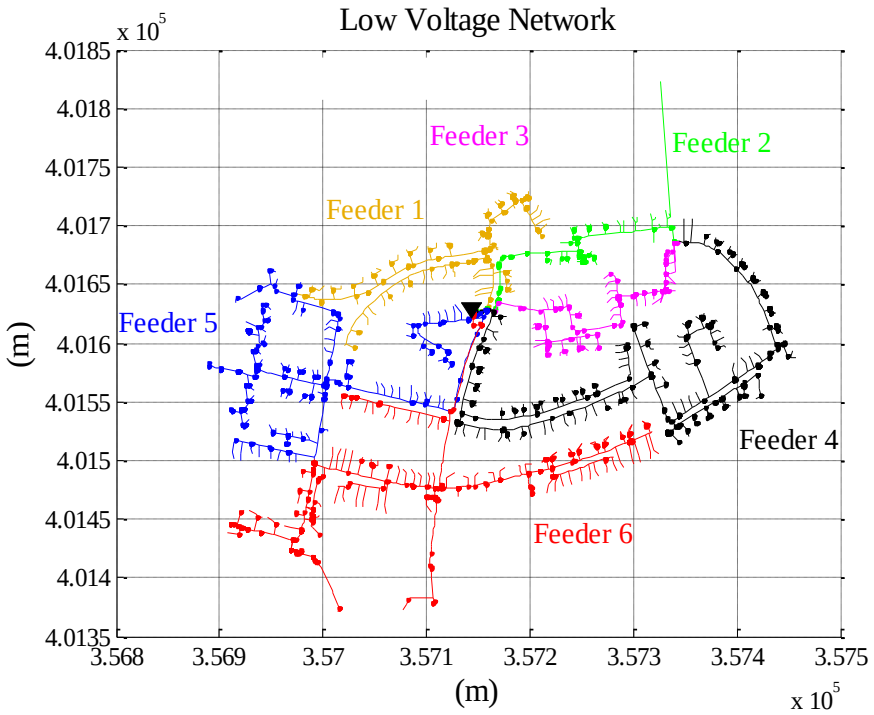
1000s

Weekday/ Winter



- Realistic **EV** load **profiles***

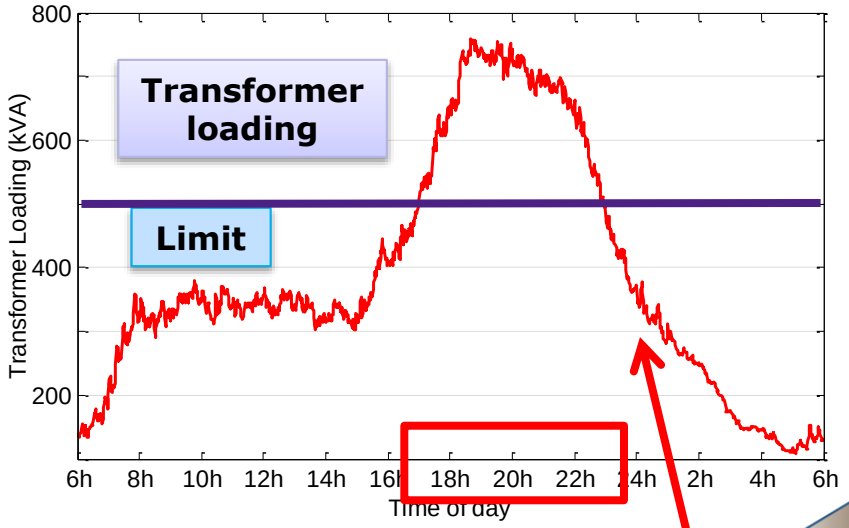
MEA Project

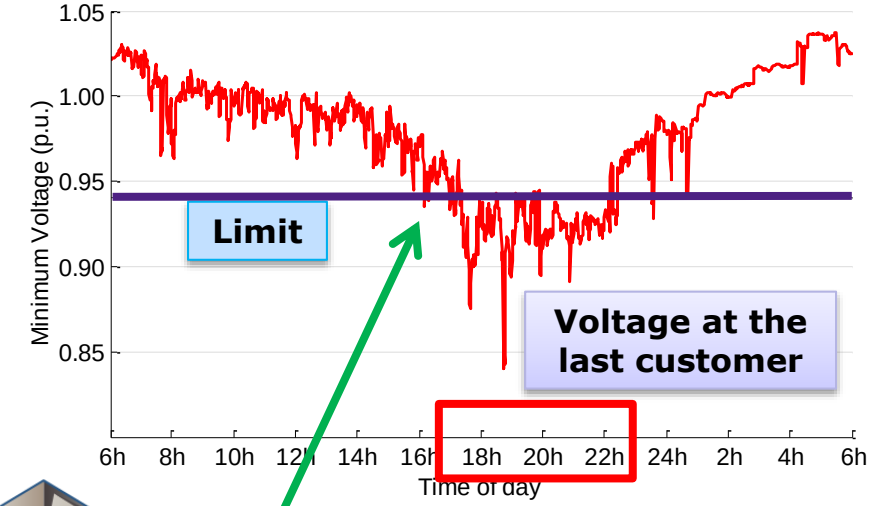


9 Real UK LV Networks

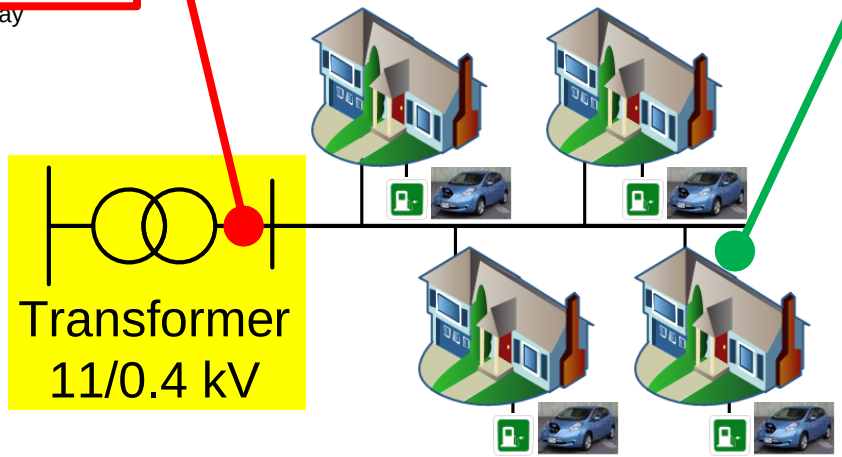
- 11kV/433V, three-phase
- Single-phase customers
- 31 LV feeders
- Main cable: 220–750m
- 2,000+ customers

Example LV Network





500 kVA transformer
370 customers
6 LV feeders
Length: 250 – 650 m

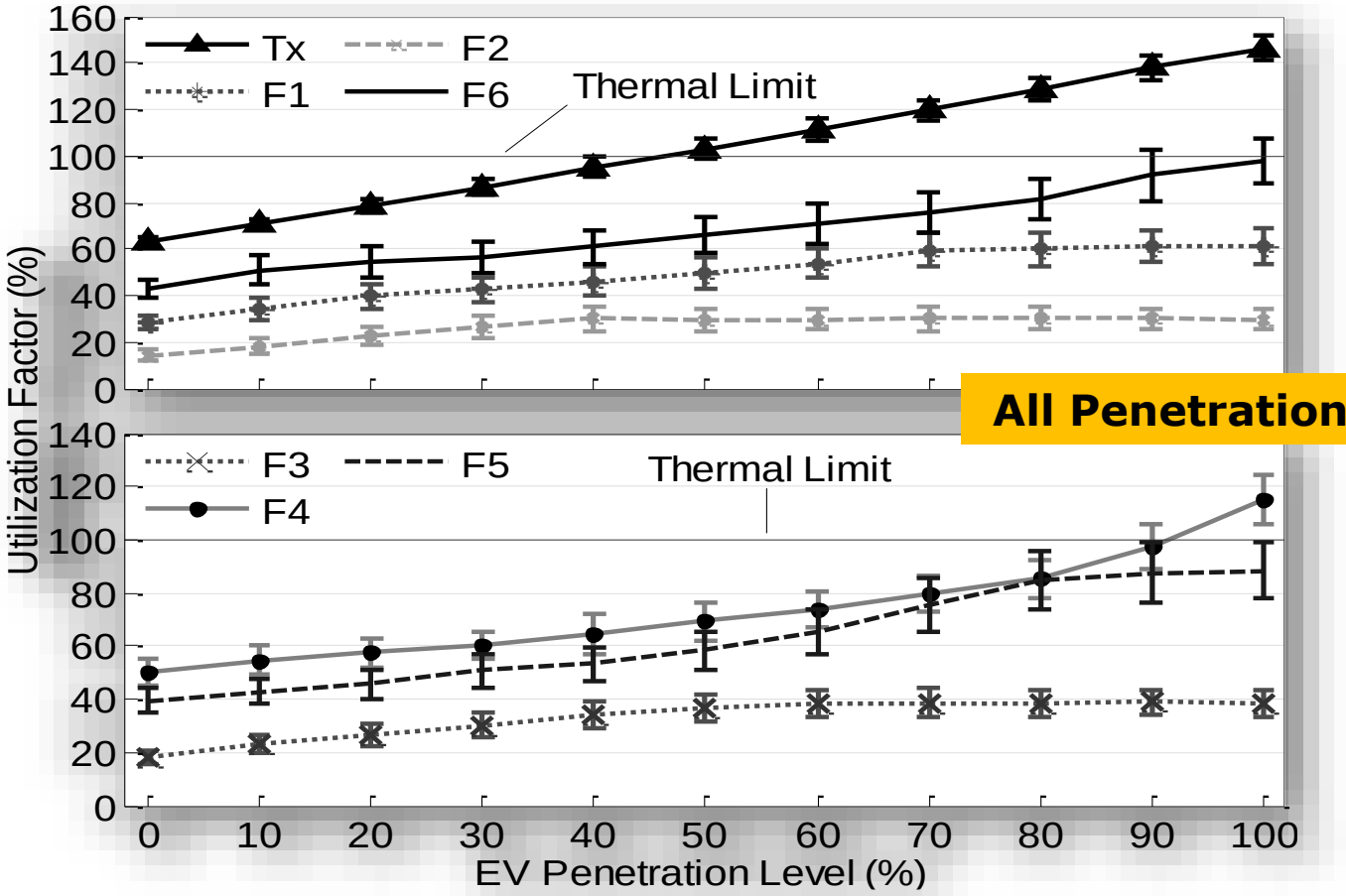


100% PV Penetration

What happens with other penetrations?
Which problem occurs first?
When problems start?

Multi-penetration and multi-network assessment

Example LV Network

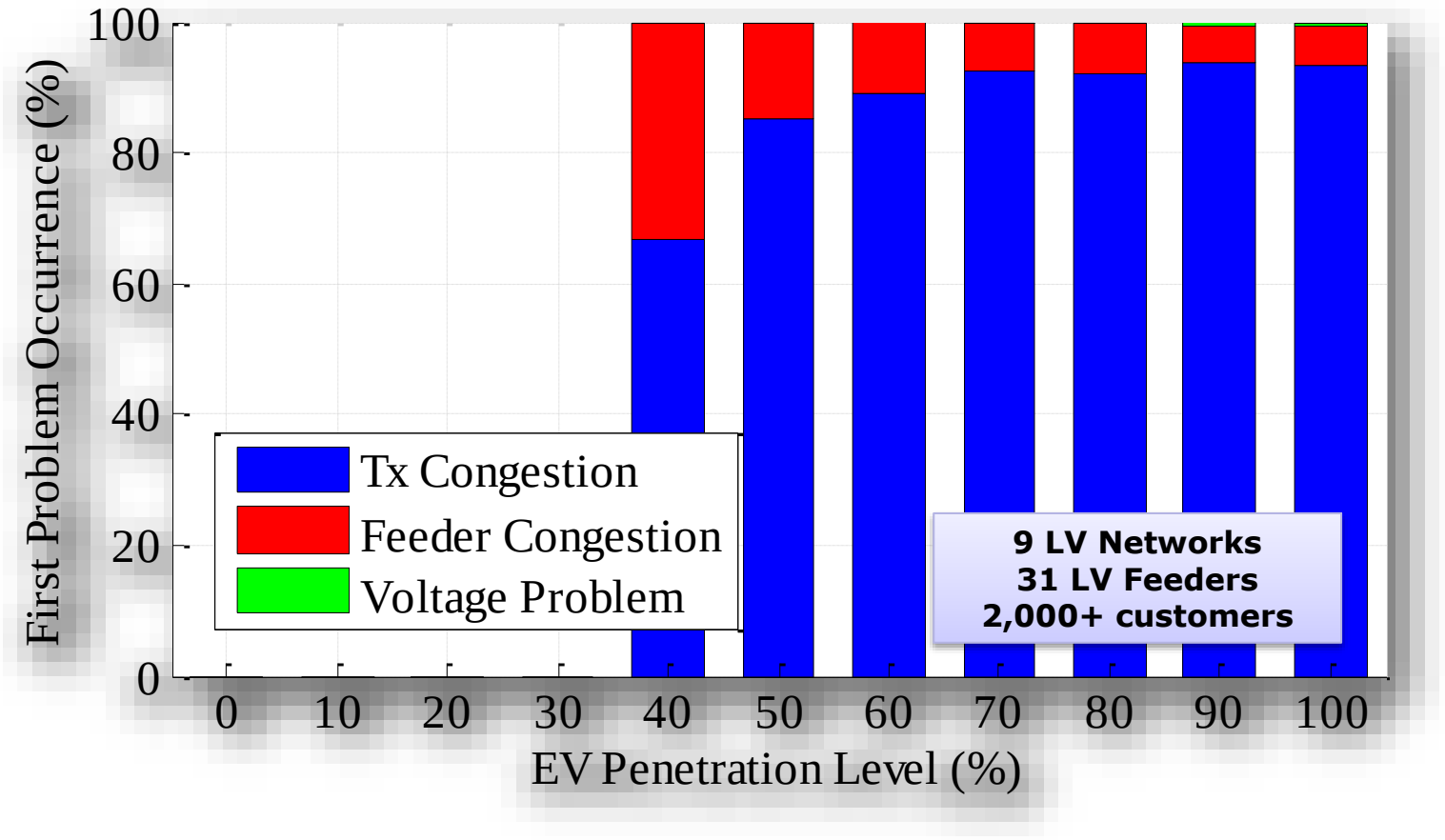


All Penetration Levels

Transformer (500 kVA) congestion appears first

Then feeders are affected (highly loaded ones)

Impact Analysis: Key Remarks



Congestion main constraint from **40% of EV penetration**

Different LV networks experience different problems

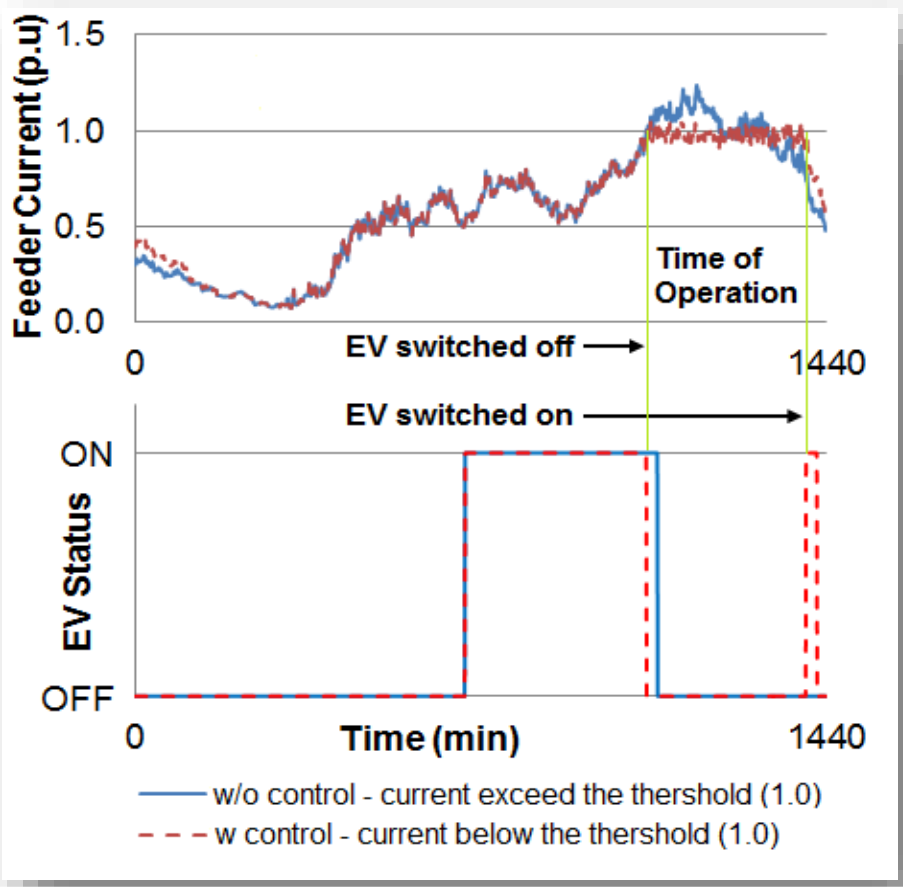
ESPRIT-Based Control

- To understand the extent to which a cost-effective and practical solution can manage EV charging points
- Stochastic Analysis (Monte Carlo) to cater for uncertainties
  - EV charging behaviour, load profile, etc.
- Metrics
  - Thermal overloads
  - Voltage issues (BS EN 50160)
  - Customer Impact Level

*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

Conceptual Approach

1. Disconnect EVCPs when problems are detected
   - Following a hierarchical (corrective) approach
2. Reconnect EVCPs when no problems are detected
   - Following a hierarchical (preventive) approach
3. Suitable selection of the EVs will be managed



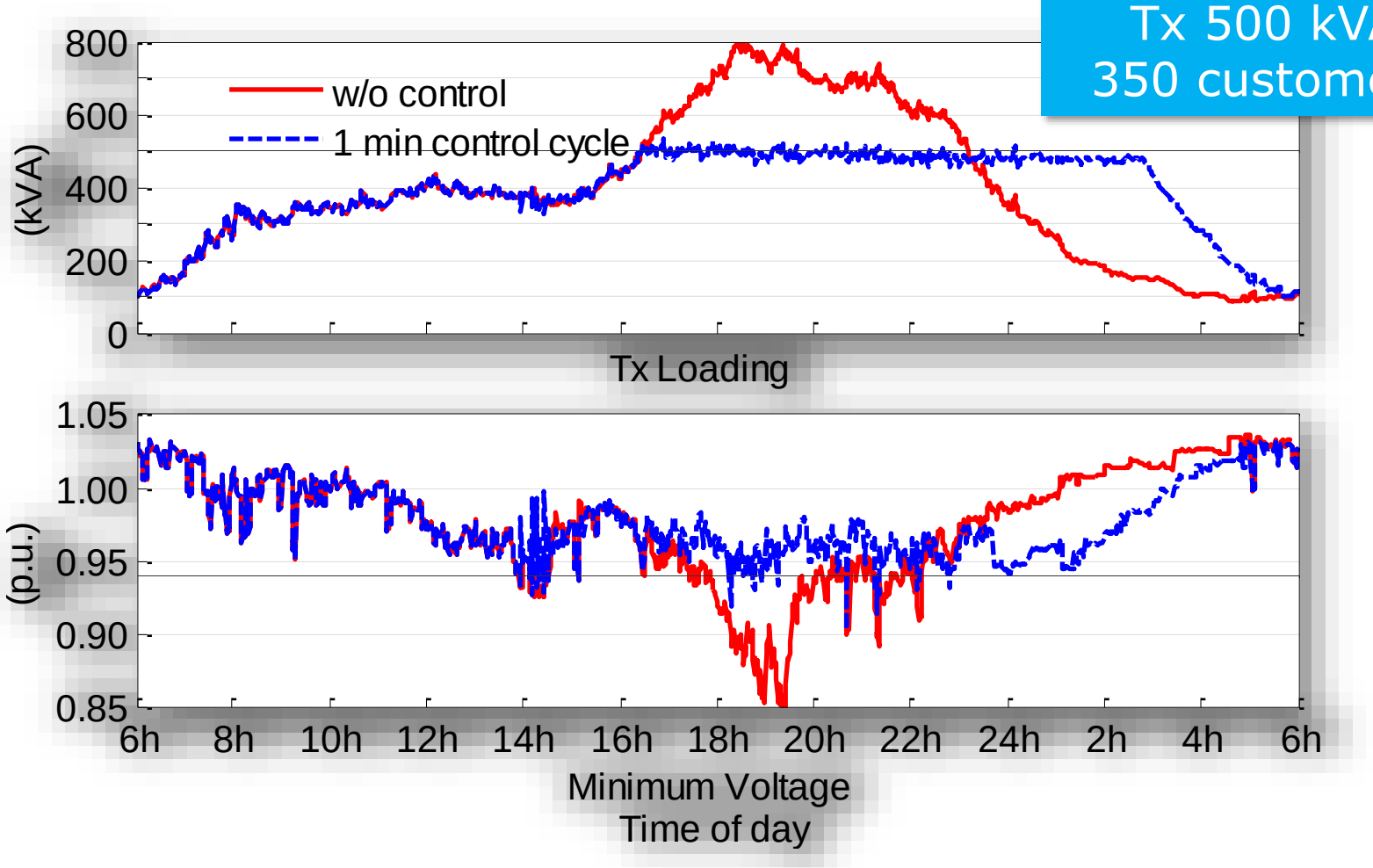
Simplest Control Algorithm → Advanced Control Algorithms

MEA progressively trialled the control algorithm

*J. Quirós-Tortós, et al, "Control of EV charging points for thermal and voltage management of LV networks," IEEE Transactions on Power Systems

Network Performance (100% EVs)

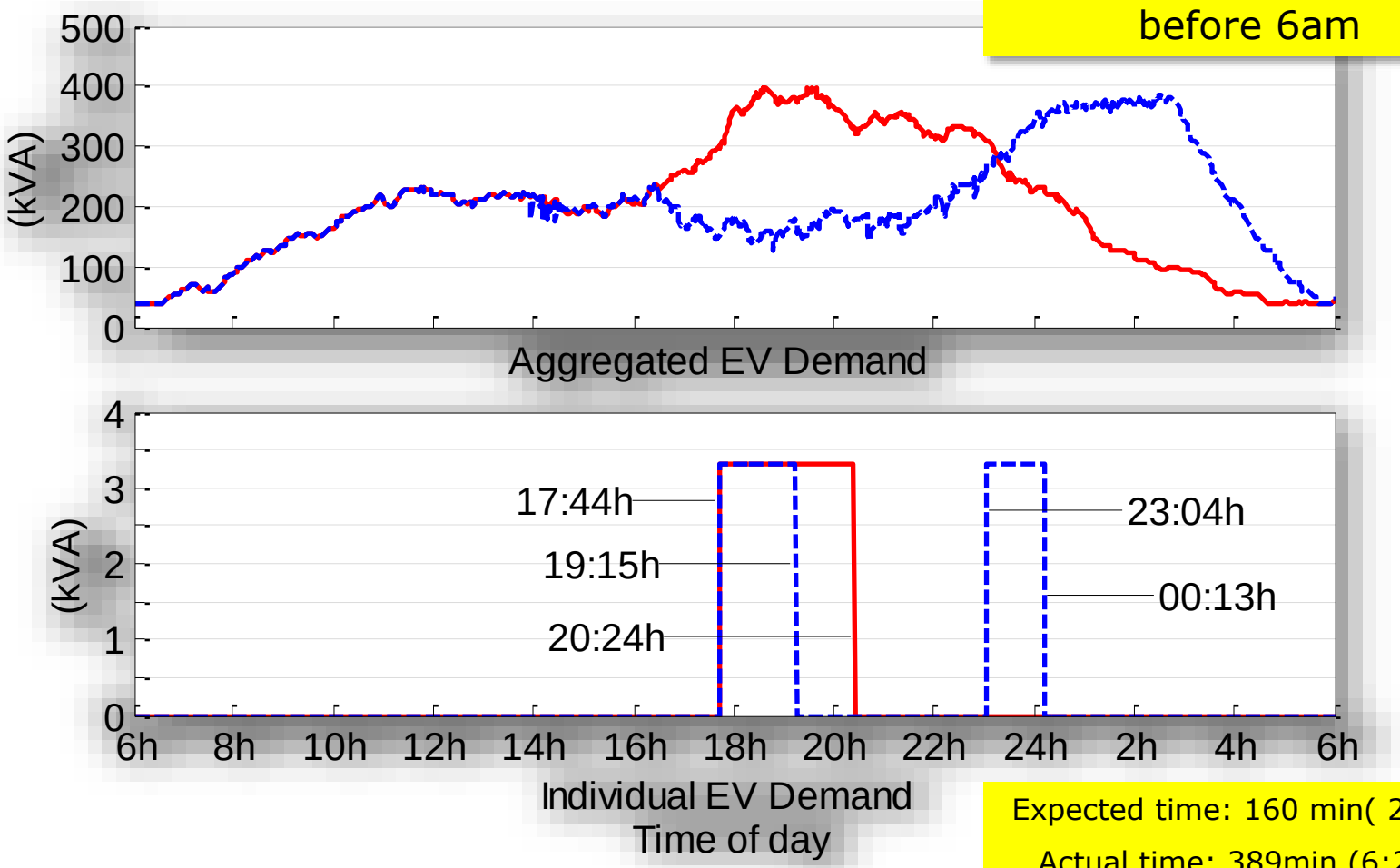
Tx 500 kVA
350 customers



1-min control cycle → Problems solved! (in theory)

Effects on EV Demand

Most EVs are charged before 6am

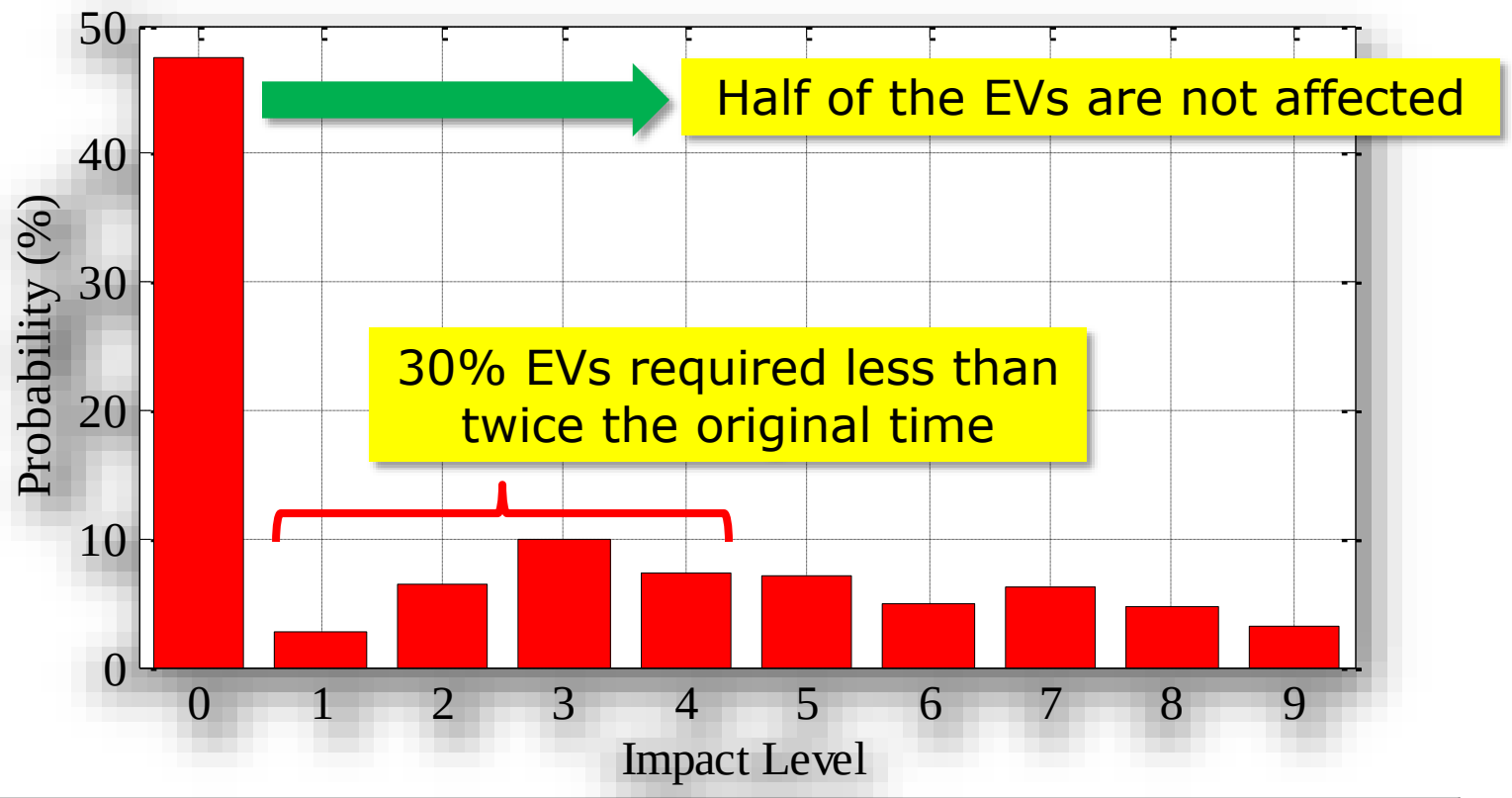


Expected time: 160 min(2:40h)

Actual time: 389min (6:29h)

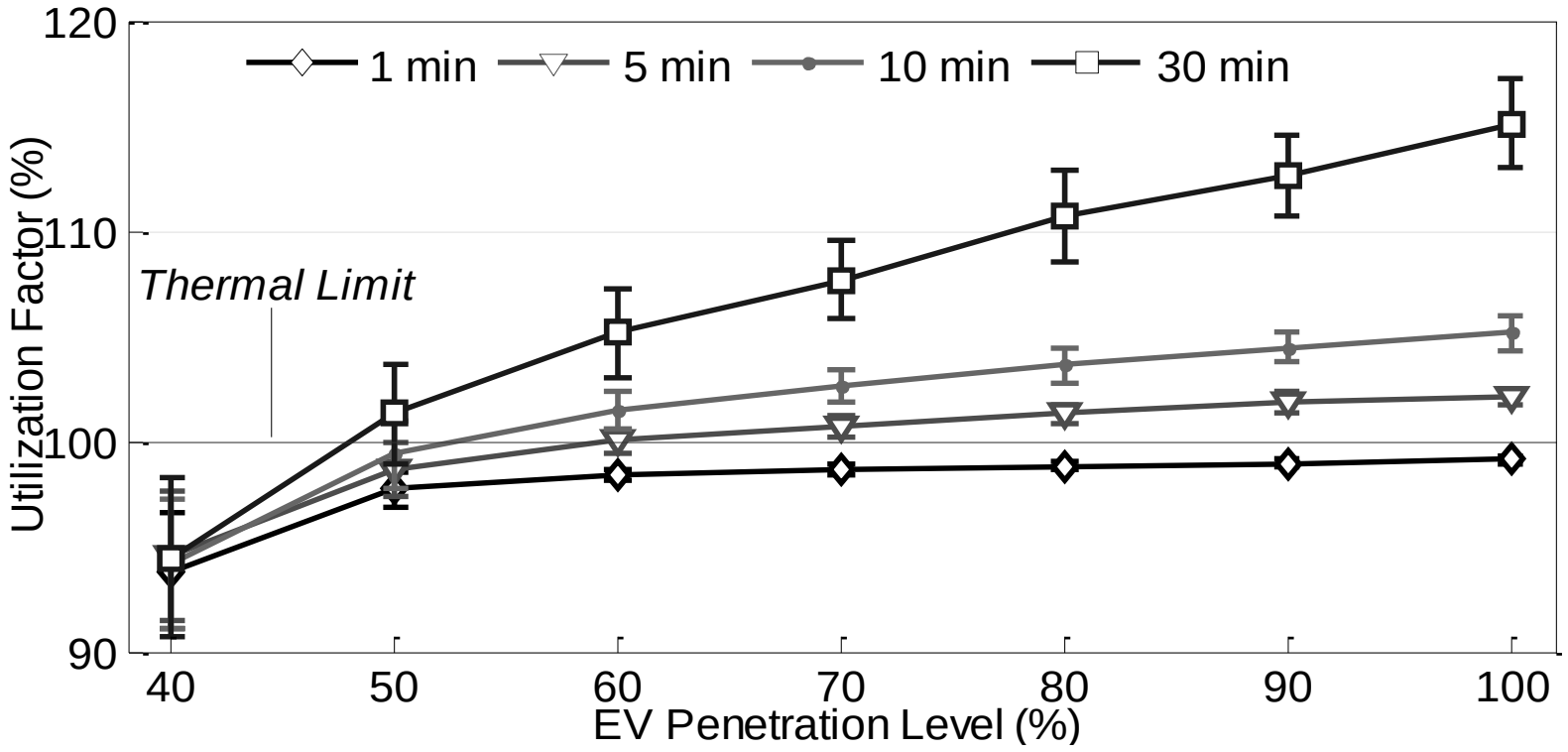
Charging Delay: 143.13%

Customer Impact Level (CIL)



Customer Impact Level	0	1	2	3	4
Additional Charging Time (%)	0	1-25	26-50	51-75	76-100
Customer Impact Level	**5**	**6**	**7**	**8**	**9**
Additional Charging Time (%)	101-125	126-150	151-175	176-200	> 200

Transformer Loading



10-min control cycle can be as effective

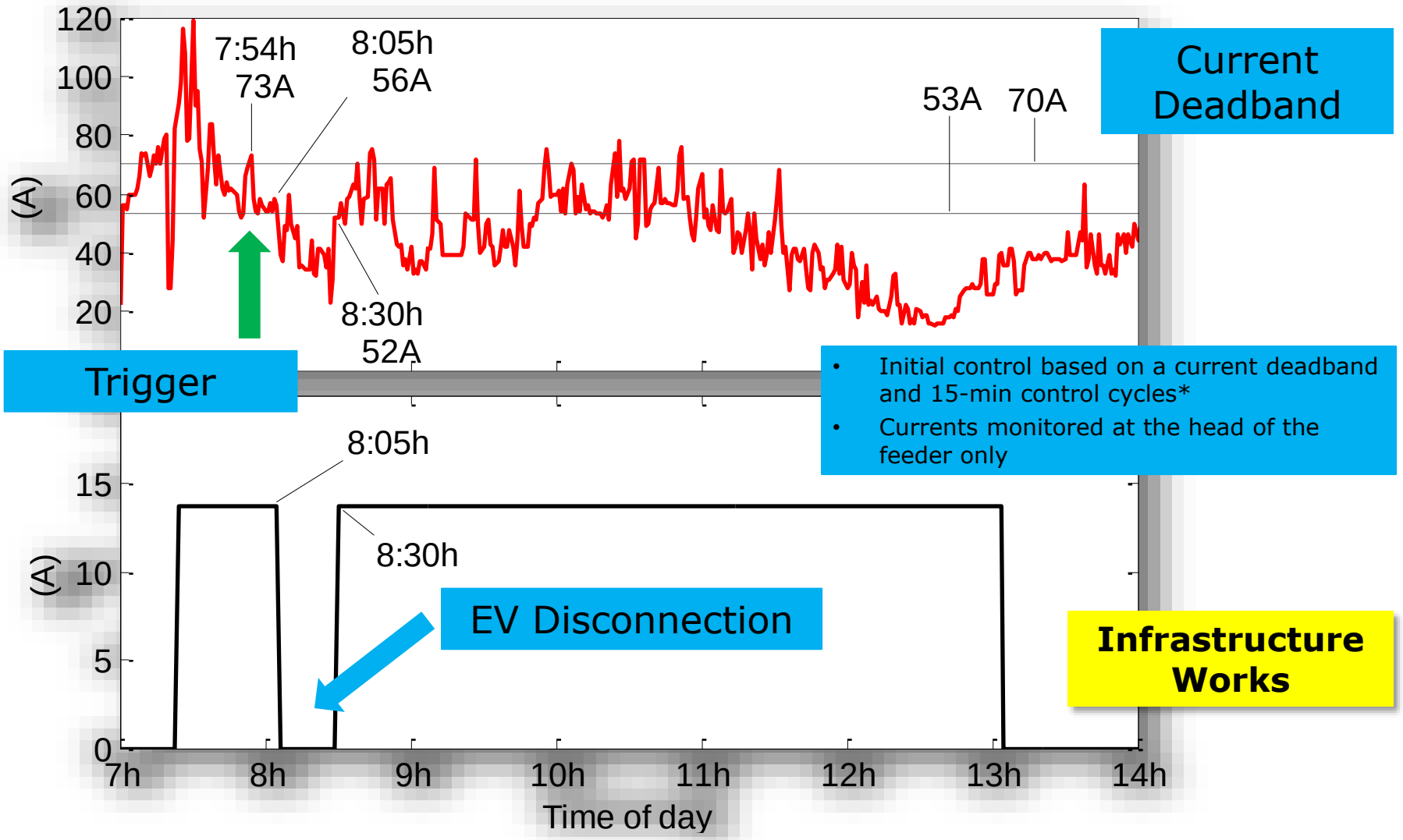
Probabilistic Assessment: CIL

Percentage of EV users w/o delay
CIL = 0

Control Cycle	EV Penetration Level (%)						
	40%	50%	60%	70%	80%	90%	100%
1 min	99	87	72	59	50	44	**40**
5 min	99	89	77	67	60	56	**51**
10 min	100	91	80	71	63	59	**54**
30 min	100	95	85	76	70	64	59

and it improves customer acceptance

ESPRIT Control: Field Example



* http://myelectricavenue.info/sites/default/files/86002_8_R_SDRC%209.7%20Issue%202.pdf

Control May 2015

ESPRIT Control: Social Acceptance

Impact of the ESPRIT Control Operation in customers **is small**

Customers are happy to compromise

→ **1 hour off** followed by **15 min on**

* http://myelectricavenue.info/sites/default/files/86002_8_R_SDRC%209.7%20Issue%202.pdf

Financial & Environmental Benefits

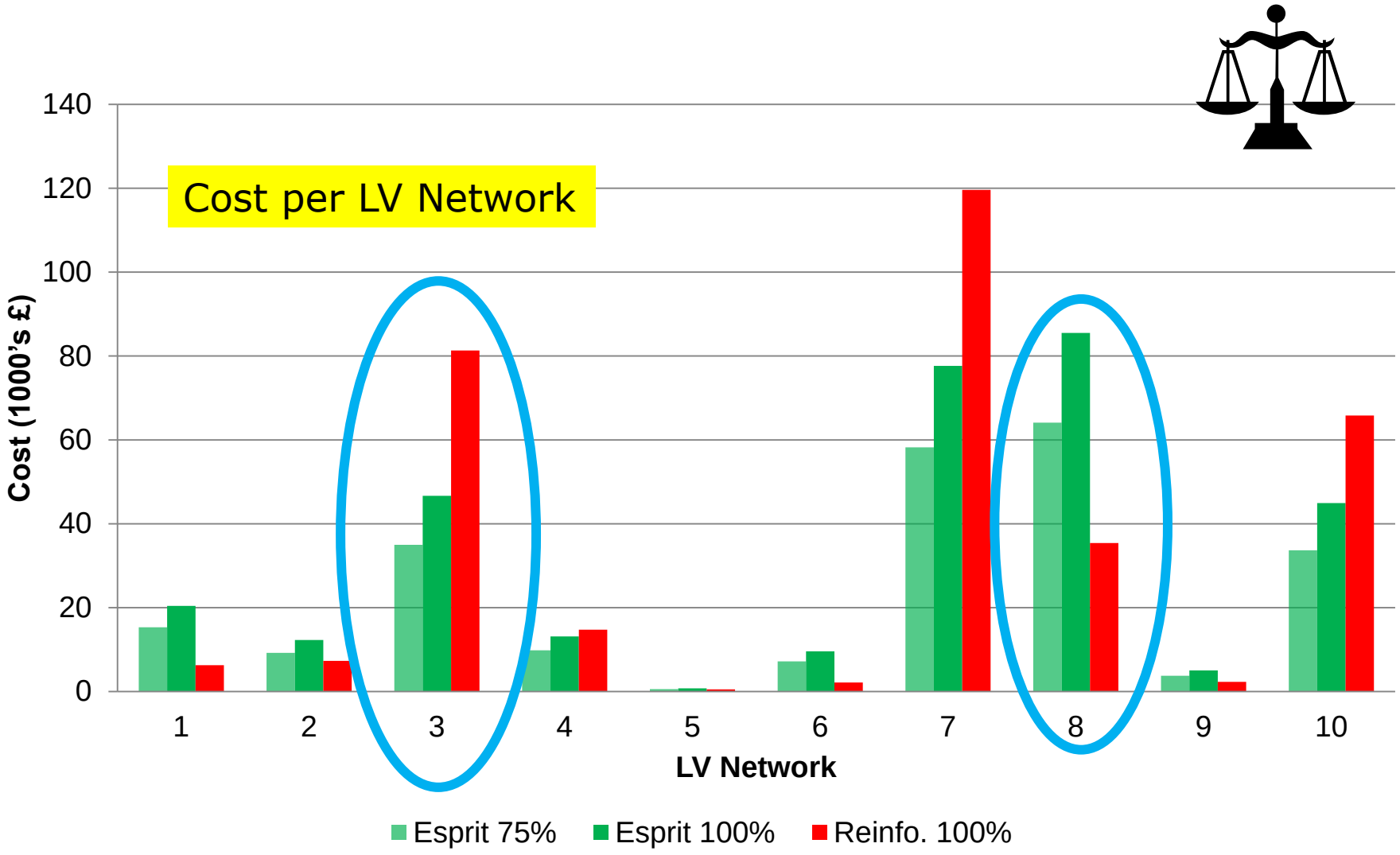
- To understand the economical savings and environmental benefits of the cost-effective and practical EV management

- Realistic and stochastic assessment
  - Actual costs, emission factors, etc.
  - On 10 LV networks (10.51% of 15030 ENWL LV Networks)
  - Compared against traditional reinforcement

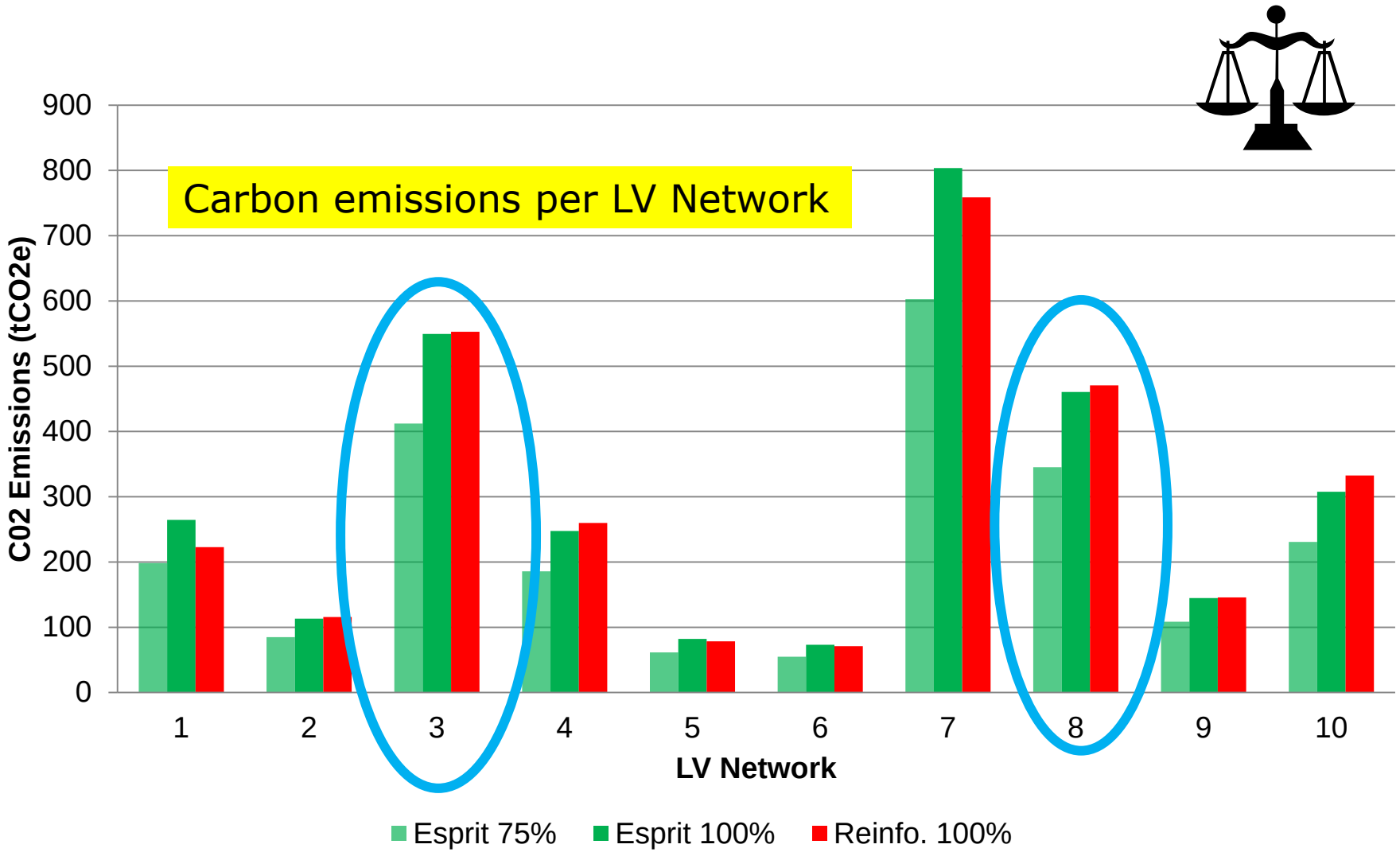
- Metrics
  - Thermal overloads
  - Voltage issues (BS EN 50160)
  - Cost (Net Present Value)
  - Carbon emissions

*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

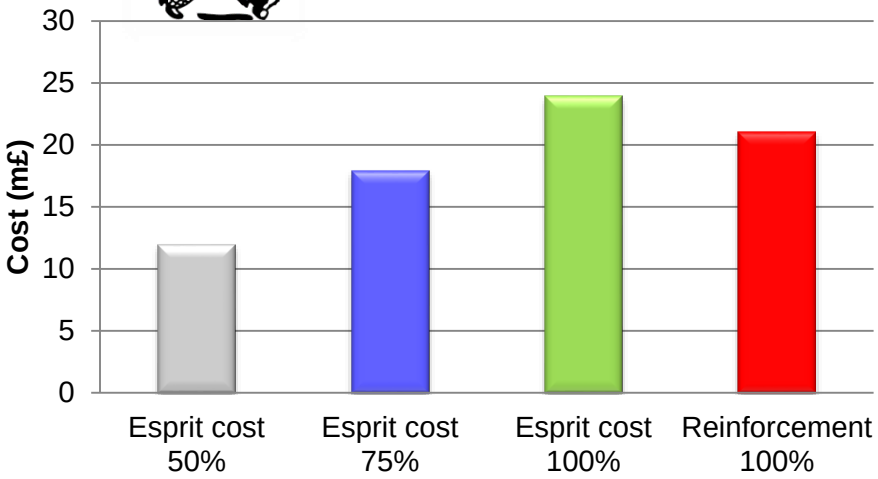
ESPRIT Control vs Reinforcement



ESPRIT Control vs Reinforcement

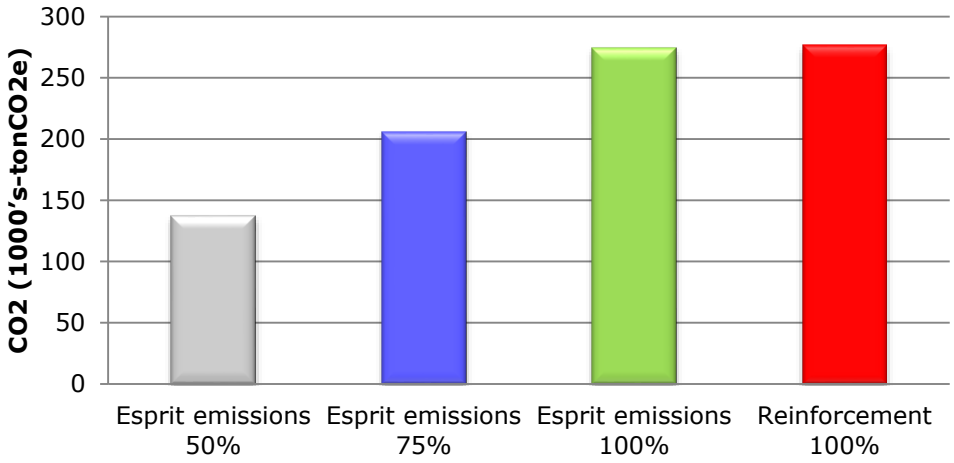


ESPRIT Control vs Reinforcement



ESPRIT cost → 75% (~3m*)

ENWL Region



ESPRIT is greener (~70,000 ton)

*For the 10.51% of studied 15030 ENWL LV Networks

Conclusions

- **Trials** are crucial to **capture** the actual EV behaviour and customer acceptance
  - Significant changes from weekday to weekend but no seasonality
  - 30% of EV users charge more than once a day

- EV **impacts** will start at ~40% of penetration (~2030)
  - Different networks will present different problems

- **ESPRIT-Based EV Management**
  - Actual trial proves the required infrastructure works
  - Practical solutions are needed in industry
  - The solution is **cheaper** and **greener** than traditional reinforcement

Technical Reports and Publications

- My Electric Avenue Project

  myelectricavenue.info

- Other Smart Grid Projects

  Technical Reports (most publicly available):

  https://sites.google.com/site/luisfochoa/publications/technical-reports

  List of Publications (most publicly available):

  Journal Papers

  https://sites.google.com/site/luisfochoa/publications/journals

  Conference Papers

  https://sites.google.com/site/luisfochoa/publications/conferences

Thanks!

Questions?

Acknowledgements

- EA Technology
- **Dr. Jairo Quiros**
  Invited Professor and Researcher
  Universidad de Costa Rica

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