Electric Vehicles as Grid Storage:

a fine-grained simulation for feasibility analysis of V2G

Mark Apperley
University of Waikato
Aotearoa New Zealand

THE UNIVERSITY OF WAIKATO

ENERGY 2013 Lisboa

Overview:

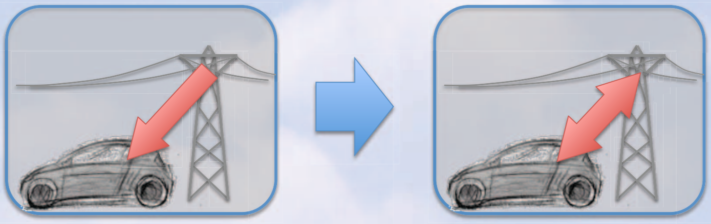
- V2G concept, motivation and issues
- New Zealand scenario
- Rationale and simulation design
- Vehicle fleet and behaviour
- Simulation results
- Implications

THE UNIVERSITY OF WAIKATO

ENERGY 2013 Lisboa 2

Vehicle to Grid (V2G) concept

- 1997 Kempton & Letendre reported detailed energy and economic analysis
- When connected to grid, EVs can be treated as both load and source

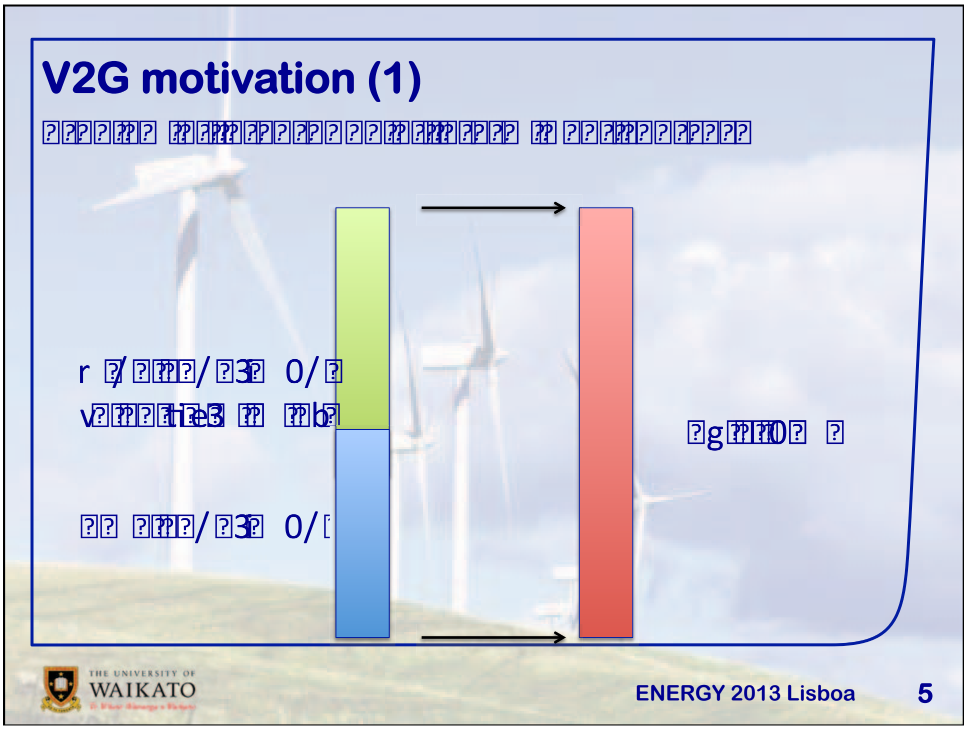


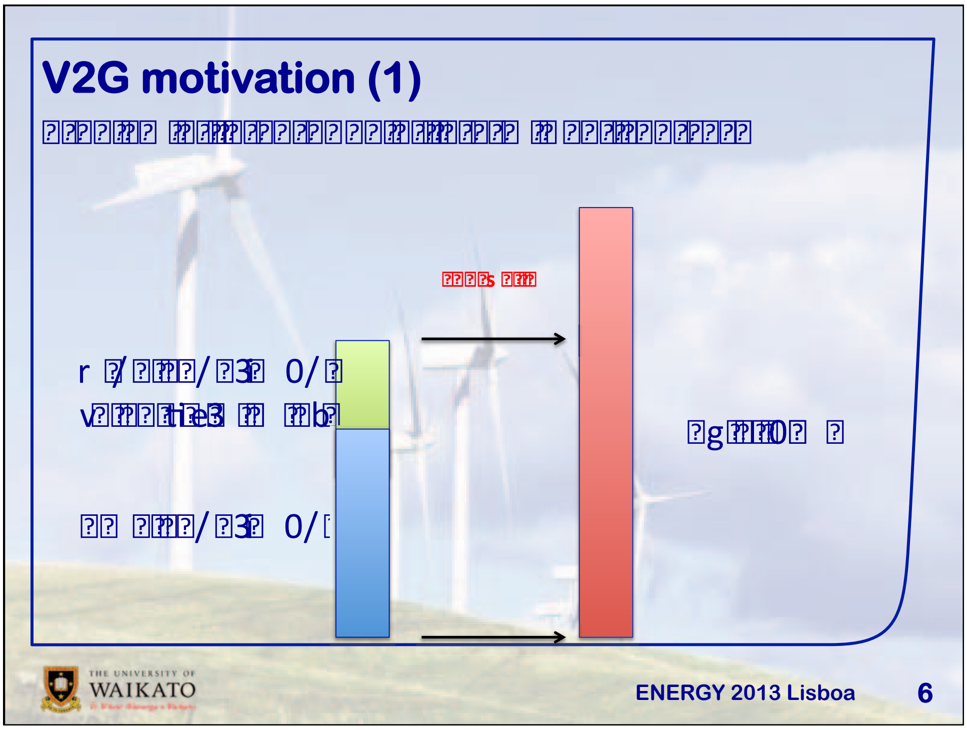
THE UNIVERSITY OF WAIKATO

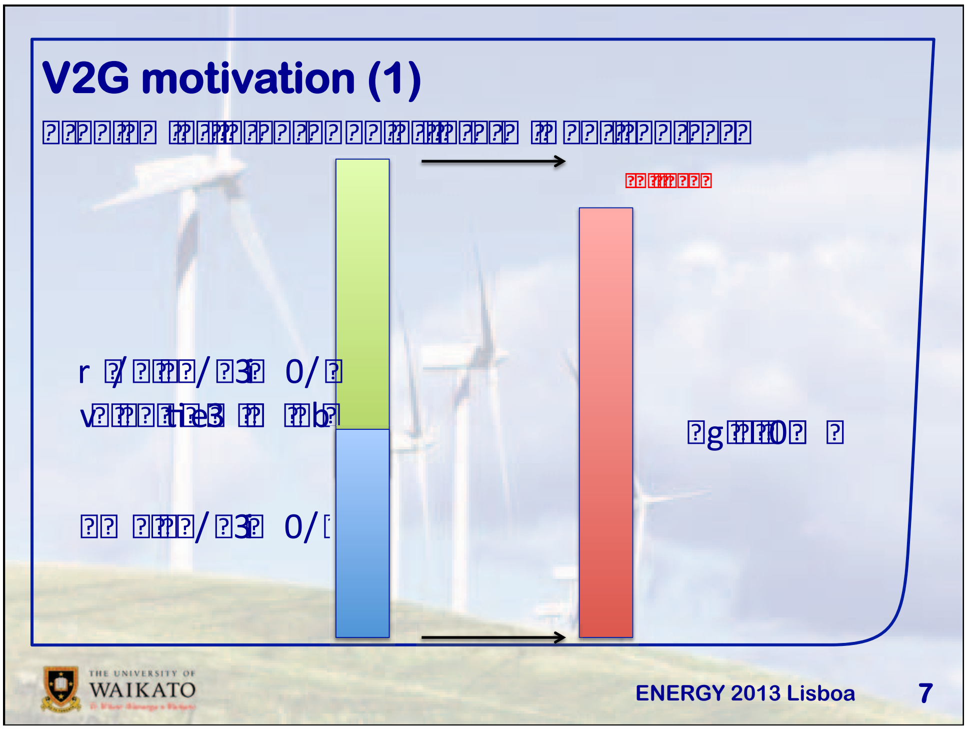
Vehicle to Grid (V2G) concept

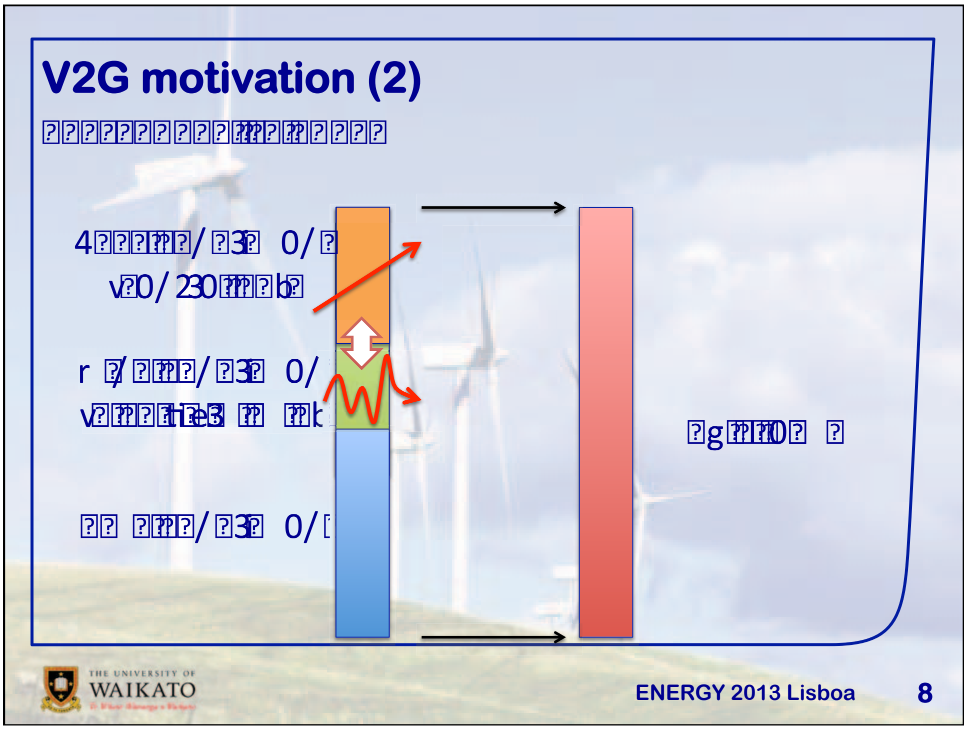
- 1997 Kempton & Letendre reported detailed energy and economic analysis
- When connected to grid, EVs can be treated as both load and source
- Need to be “plugged-in” whenever not in use
- Need to know about immediate future requirements

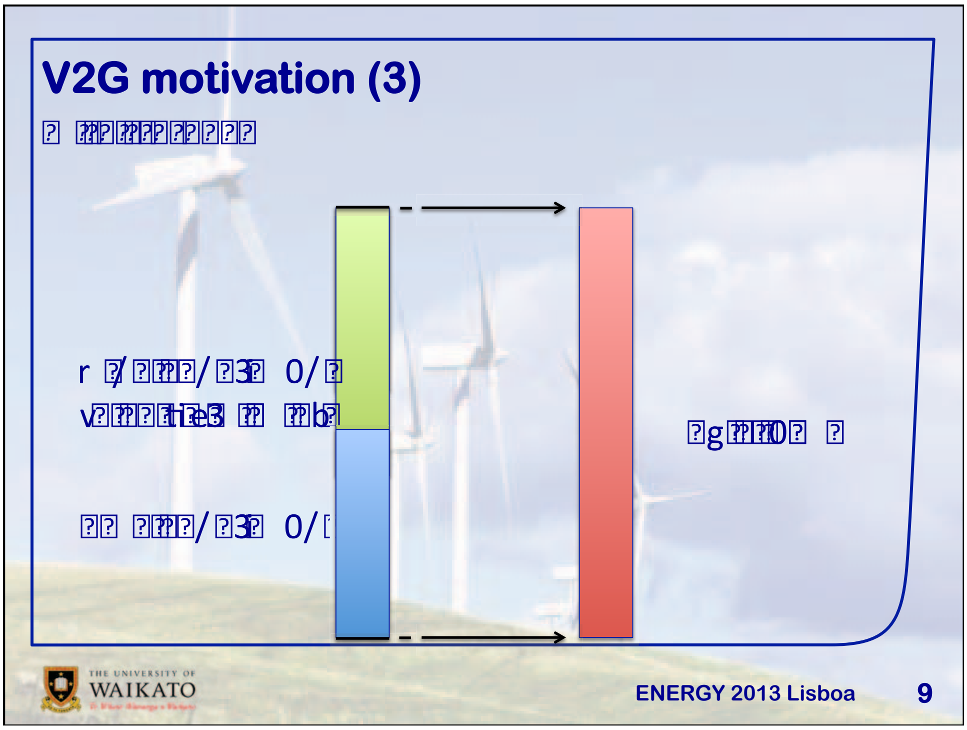
THE UNIVERSITY OF WAIKATO

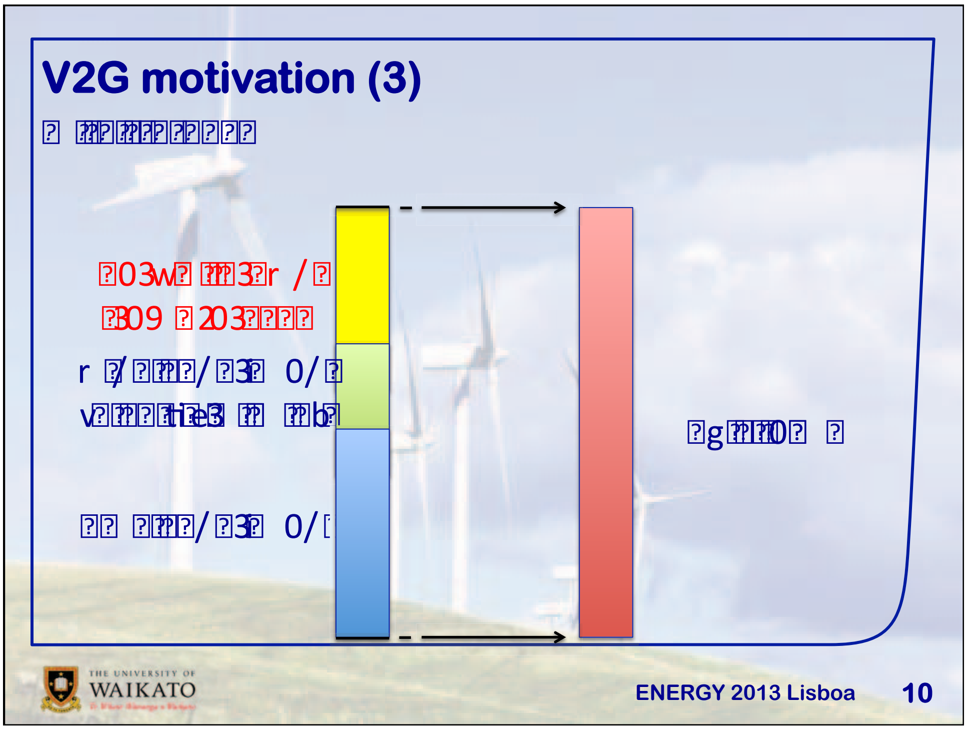

V2G motivation (1)
ENERGY 2013 Lisboa
5

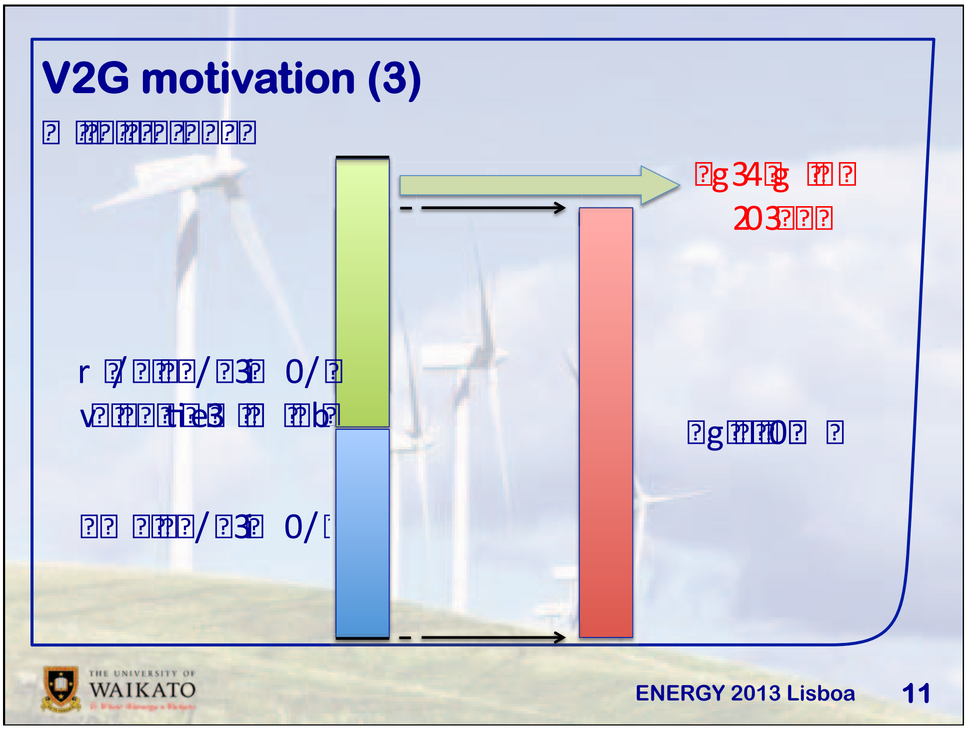

V2G motivation (1)
ENERGY 2013 Lisboa
6

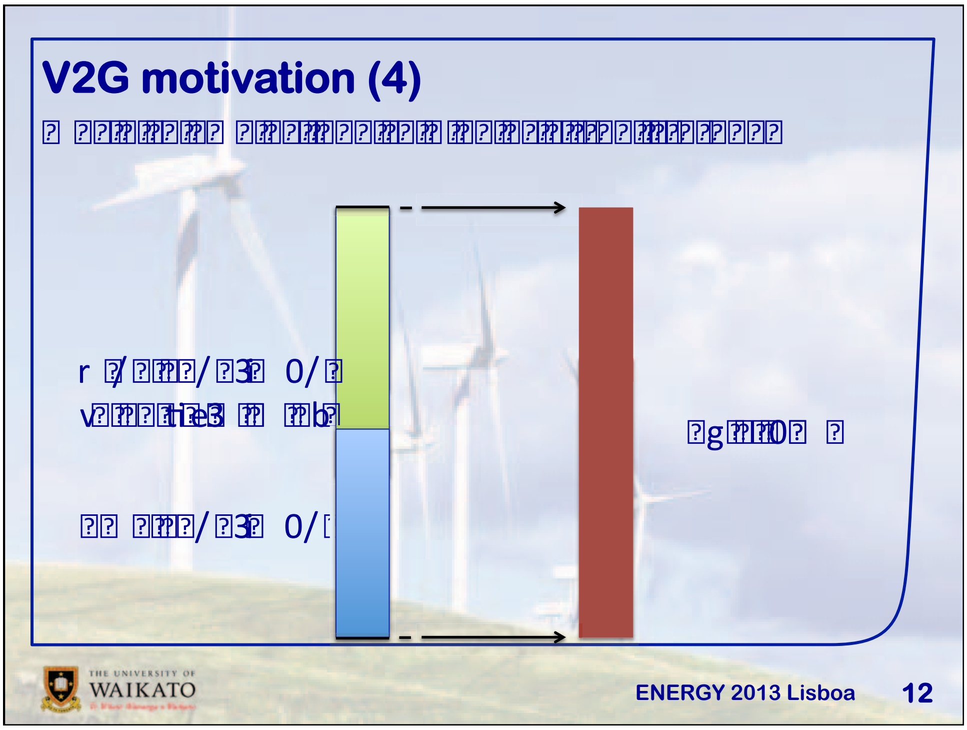

V2G motivation (1)
THE UNIVERSITY OF
WAIKATO
ENERGY 2013 Lisboa
7

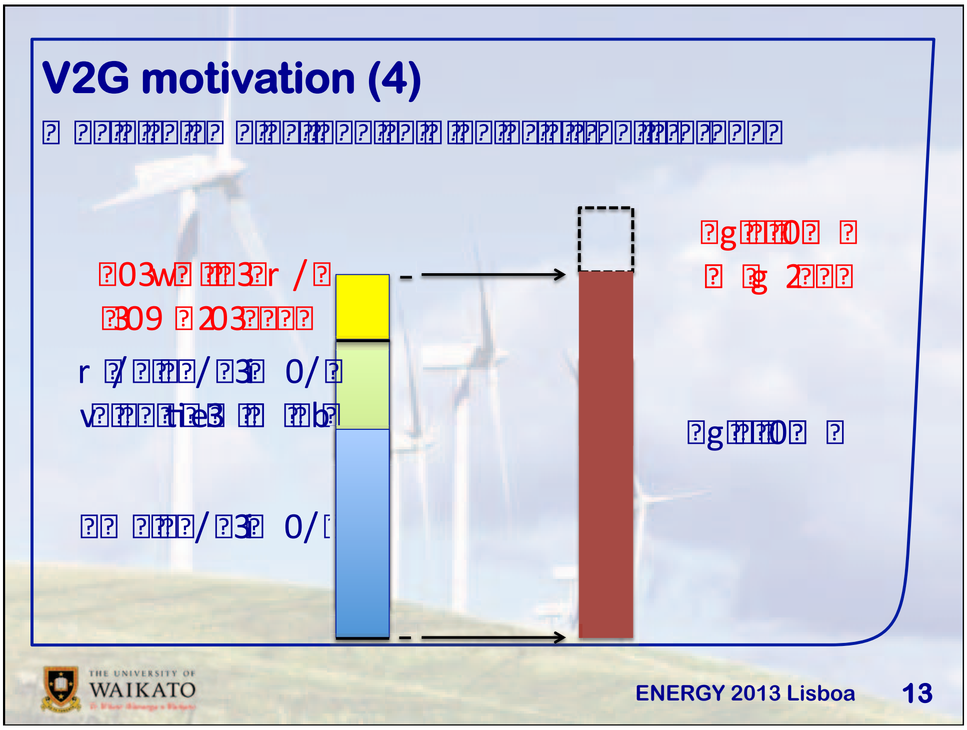

V2G motivation (2)
THE UNIVERSITY OF
WAIKATO
ENERGY 2013 Lisboa
8

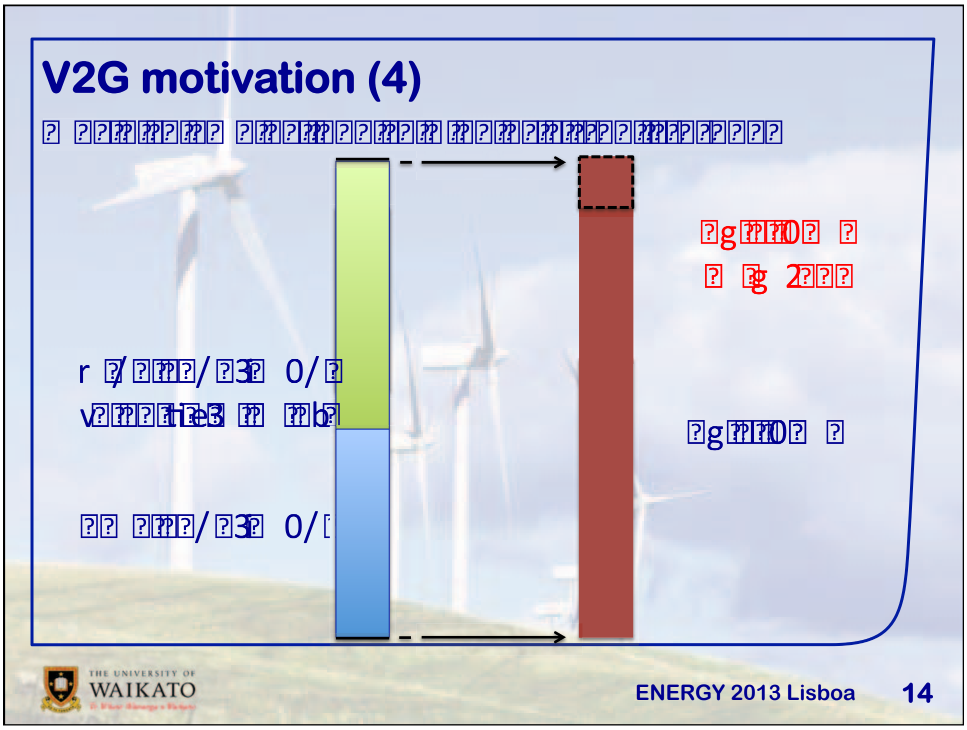

V2G motivation (3)
THE UNIVERSITY OF WAIKATO
ENERGY 2013 Lisboa
9

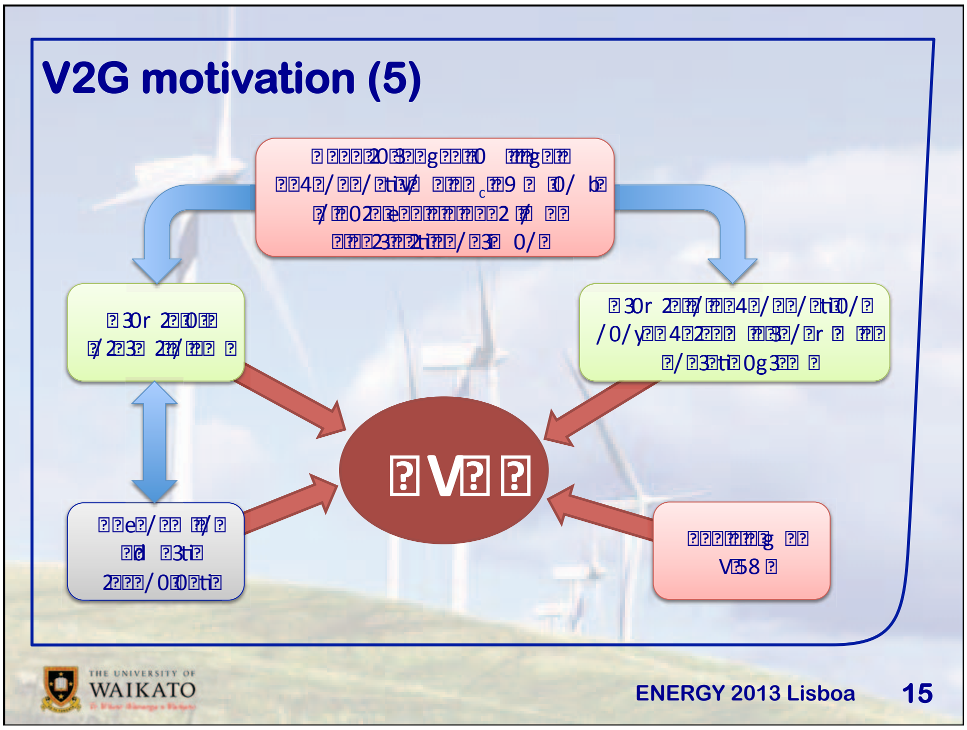

V2G motivation (3)
THE UNIVERSITY OF WAIKATO
ENERGY 2013 Lisboa
10

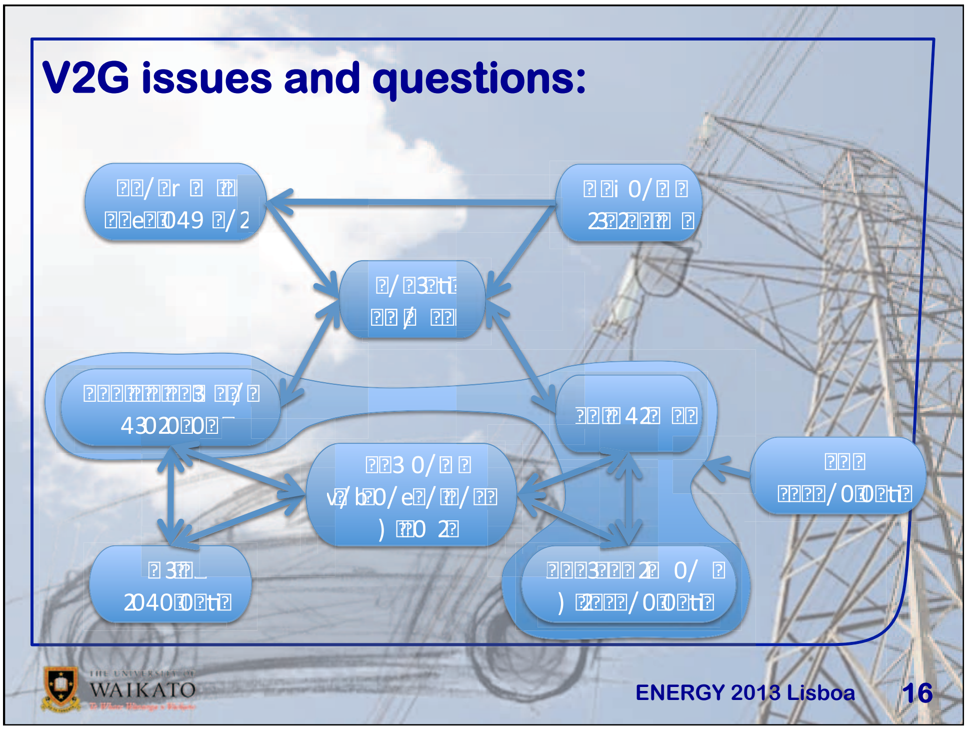

V2G motivation (3)
THE UNIVERSITY OF
WAIKATO
ENERGY 2013 Lisboa
11

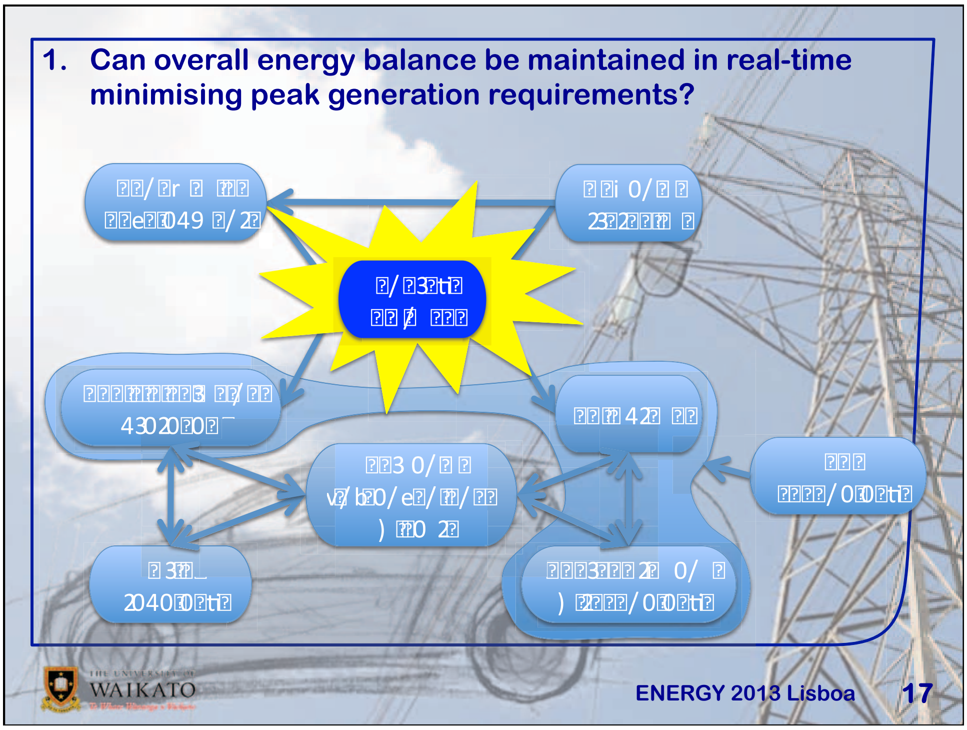

V2G motivation (4)
THE UNIVERSITY OF
WAIKATO
ENERGY 2013 Lisboa
12


V2G motivation (4)
THE UNIVERSITY OF WAIKATO
ENERGY 2013 Lisboa
13

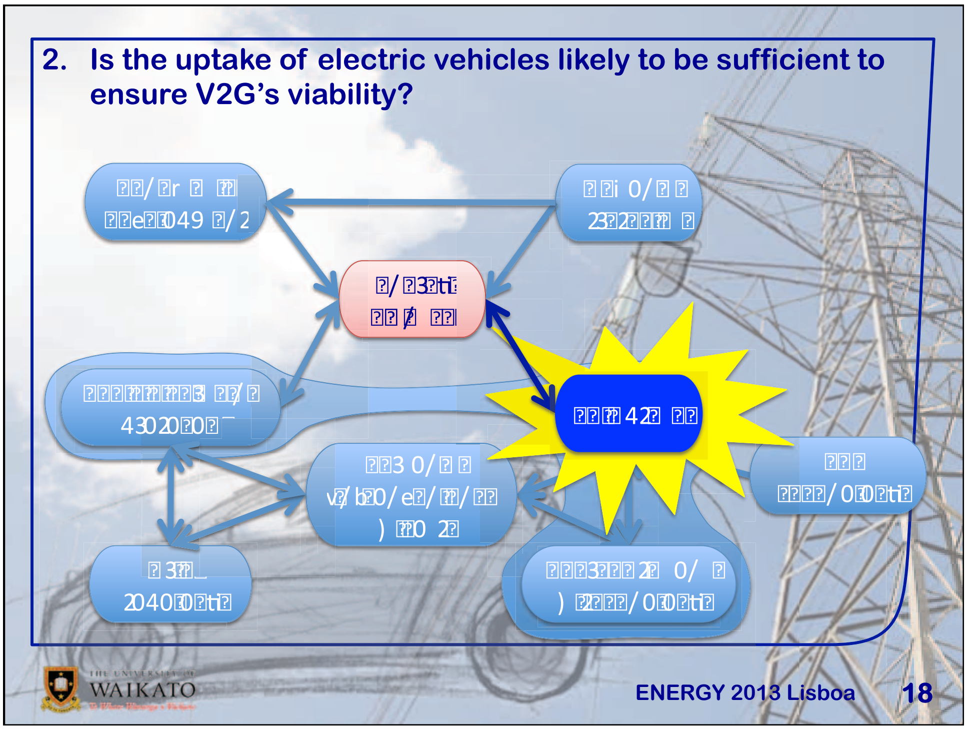

V2G motivation (4)
THE UNIVERSITY OF WAIKATO
ENERGY 2013 Lisboa
14


V2G motivation (5)
WAIKATO
ENERGY 2013 Lisboa
15

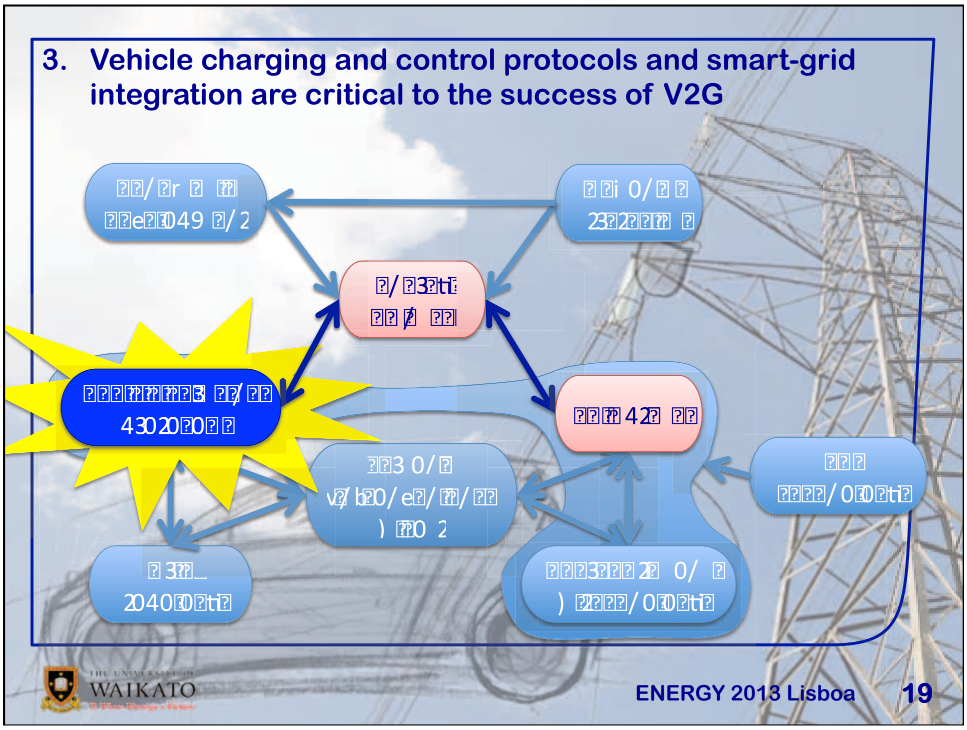

V2G issues and questions:
WAIKATO
ENERGY 2013 Lisboa
16

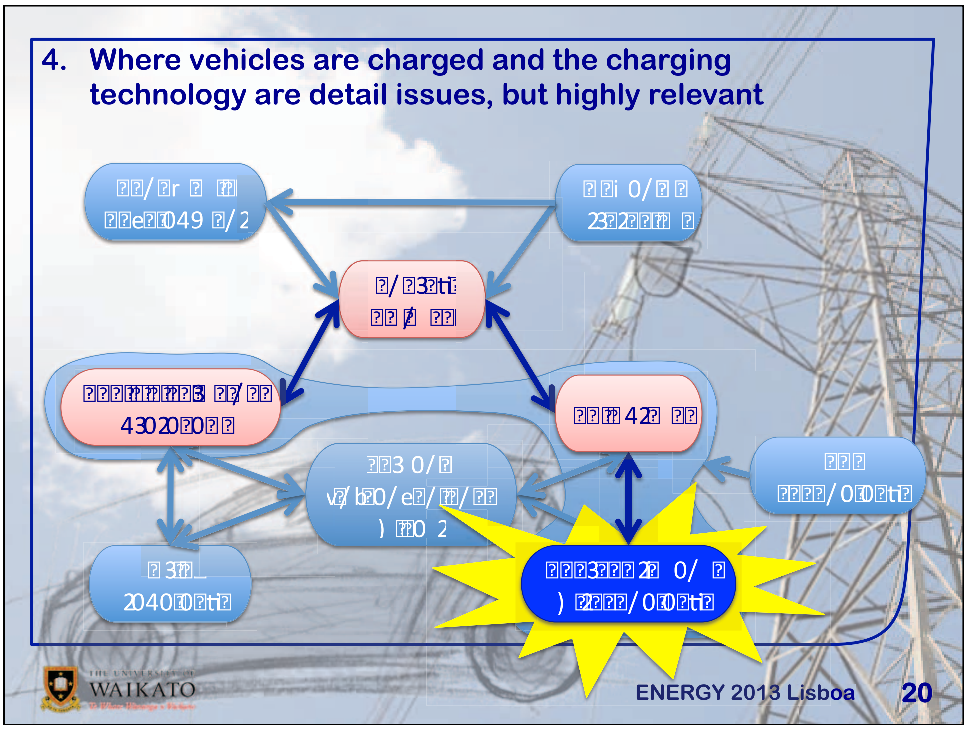


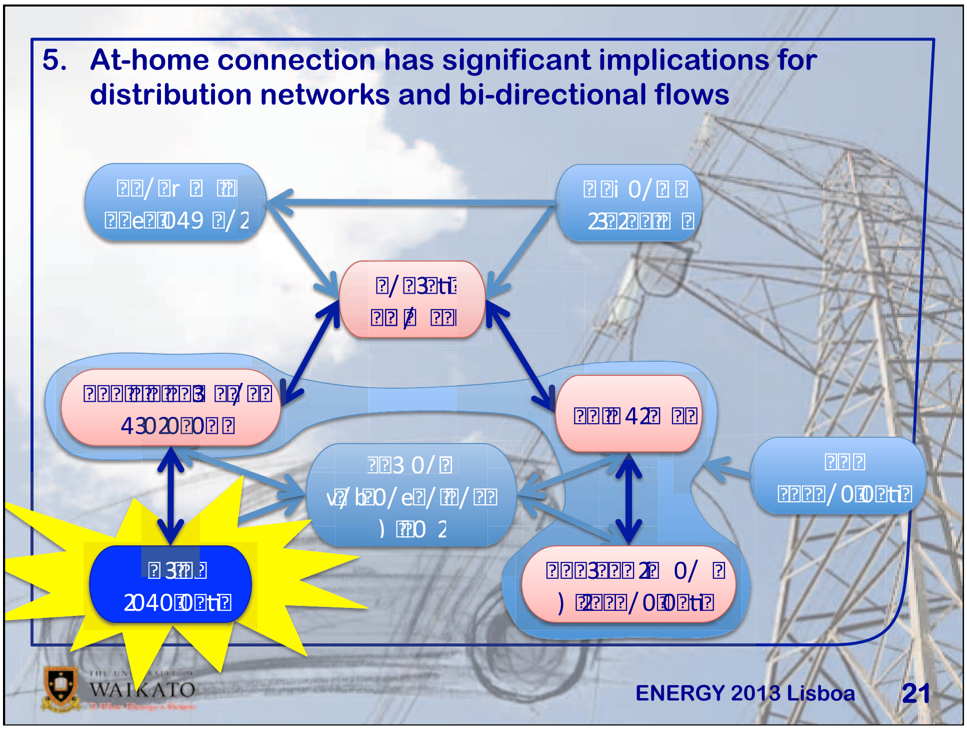
1. Can overall energy balance be maintained in real-time minimising peak generation requirements?
WAIKATO
ENERGY 2013 Lisboa
17

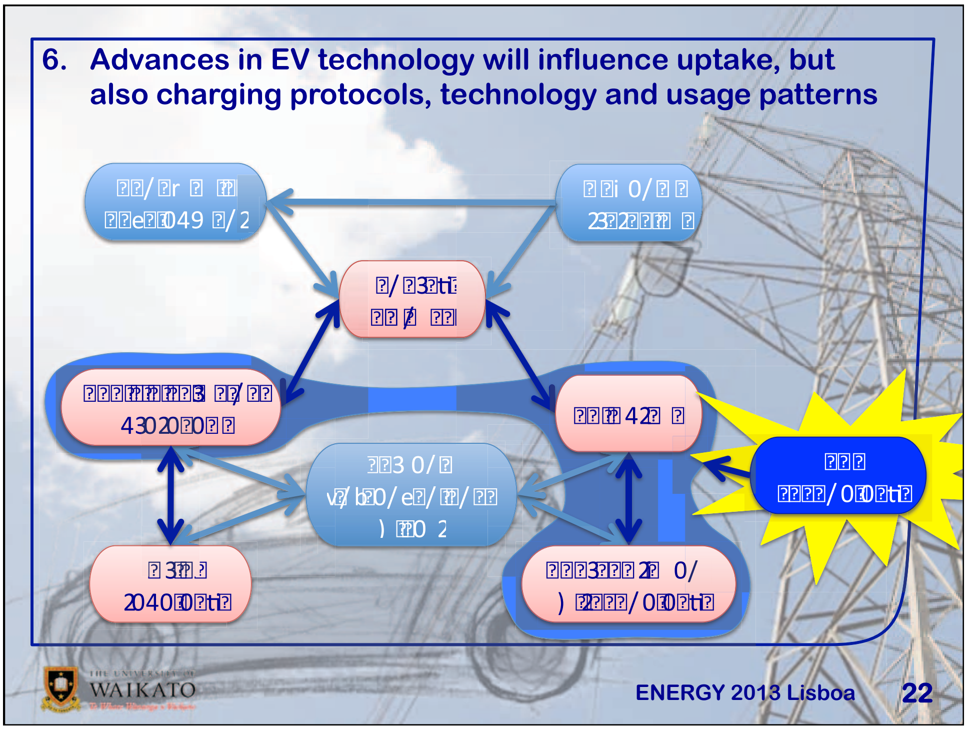


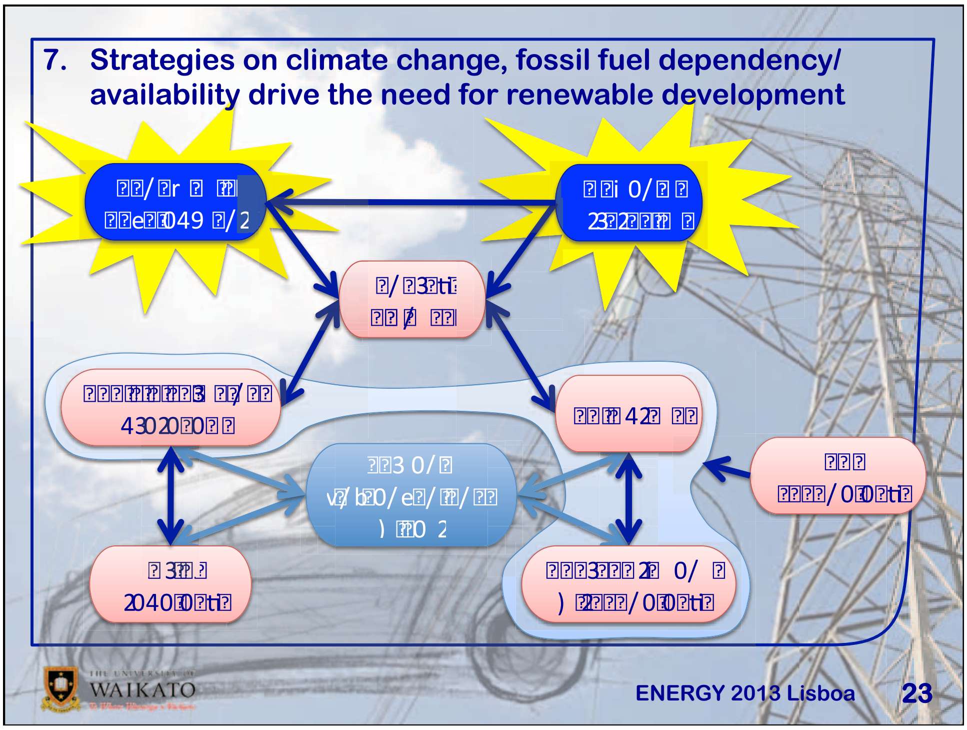
2. Is the uptake of electric vehicles likely to be sufficient to ensure V2G's viability?
WAIKATO
ENERGY 2013 Lisboa
18

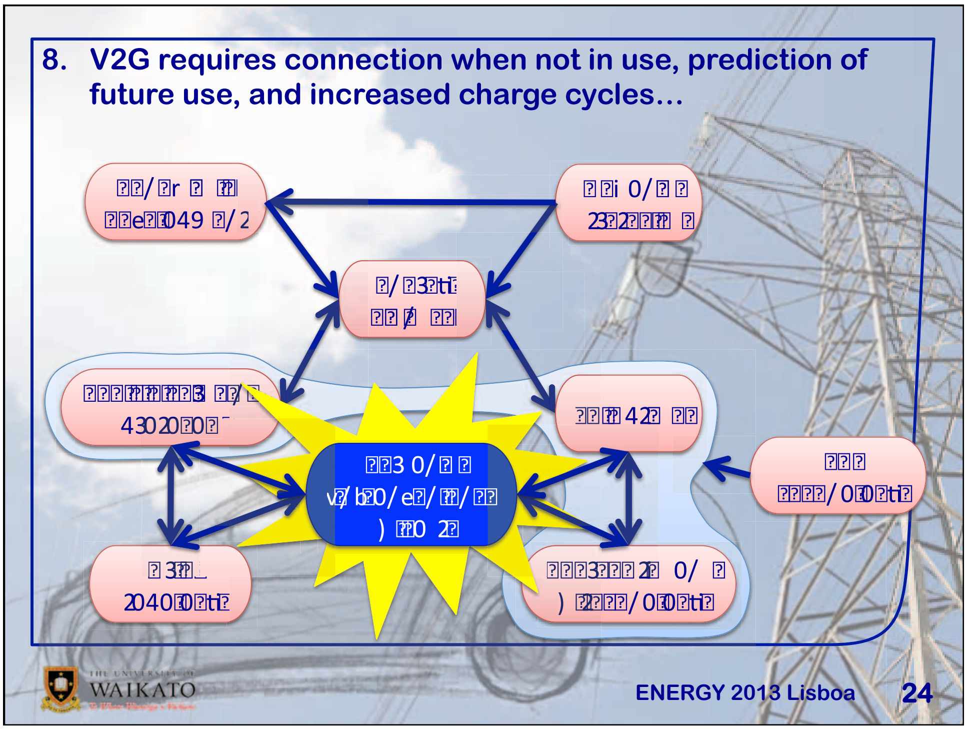

3. Vehicle charging and control protocols and smart-grid integration are critical to the success of V2G
WAIKATO
ENERGY 2013 Lisboa
19


4. Where vehicles are charged and the charging technology are detail issues, but highly relevant
WAIKATO
ENERGY 2013 Lisboa
20

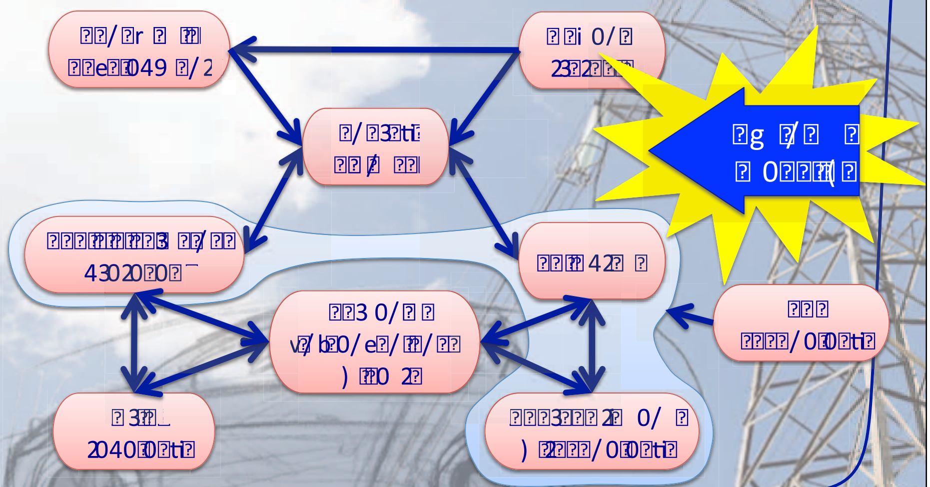

5. At-home connection has significant implications for distribution networks and bi-directional flows
WAIKATO
ENERGY 2013 Lisboa
21


6. Advances in EV technology will influence uptake, but also charging protocols, technology and usage patterns
WAIKATO
ENERGY 2013 Lisboa
22


7. Strategies on climate change, fossil fuel dependency/ availability drive the need for renewable development
WAIKATO
ENERGY 2013 Lisboa
23


8. V2G requires connection when not in use, prediction of future use, and increased charge cycles…
WAIKATO
ENERGY 2013 Lisboa
24

9. V2G disruptive technology, appropriate business models need careful shaping

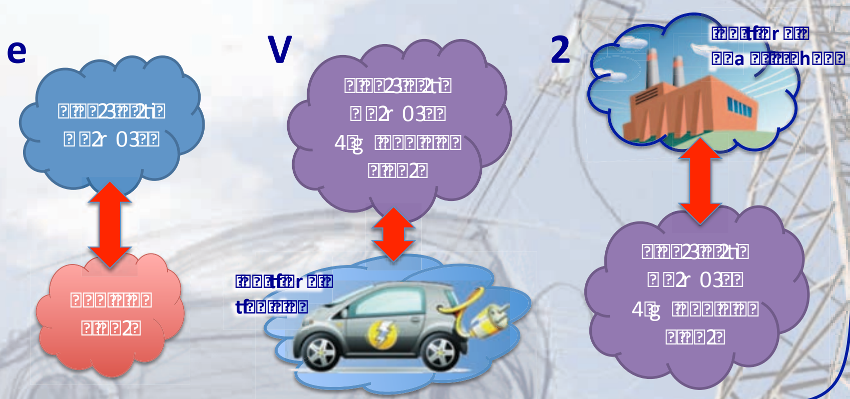


What is already known about V2G?

- Renewable integration potential demonstrated
- System issues eg distribution network topology, frequency stability
- Economic, social and business models
- Connection management techniques and protocols
- Small scale trials
- Large scale trials proposed

What is already known about V2G?

- Modelling tends to have been aggregate, short time period, or coarse time scale:



WAIKATO

ENERGY 2013 Lisboa 27

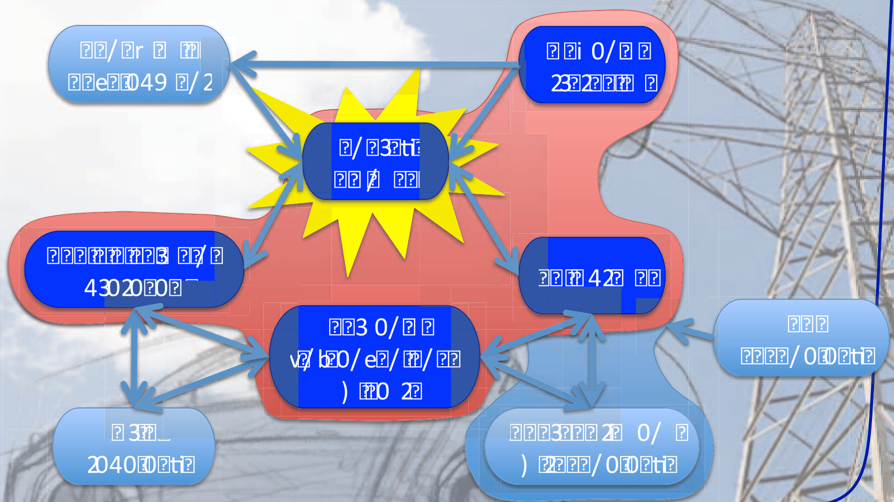
NZ model : focus is energy balance

- Can V2G deliver improved renewable integration in the New Zealand environment?
- What are the implications:
  - for the electricity system as a whole
  - for vehicle owners
  - for achieving energy strategy goals
- Fine grained & detailed simulation
  - individual components
  - short clock tick, full year duration
- Real data for wind and demand, up to 1M individual vehicles based on statistical model

WAIKATO

ENERGY 2013 Lisboa 28

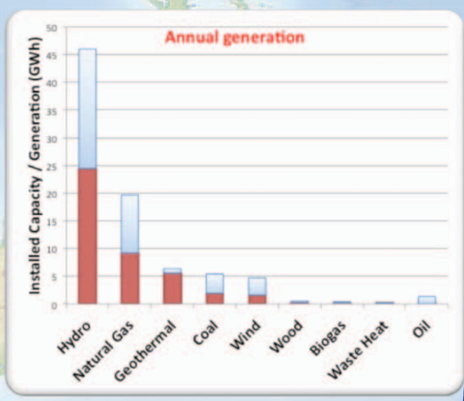
Focus on energy balance



WAIKATO

New Zealand electricity scenario

- 9.4 GW capacity
- 43 TWh/year generation (~50% capacity)
- 74% renewables
  - hydro (56%)
  - geothermal (13%)
  - wind (4%)
- 40% wind farm capacity factor



THE UNIVERSITY OF WAIKATO

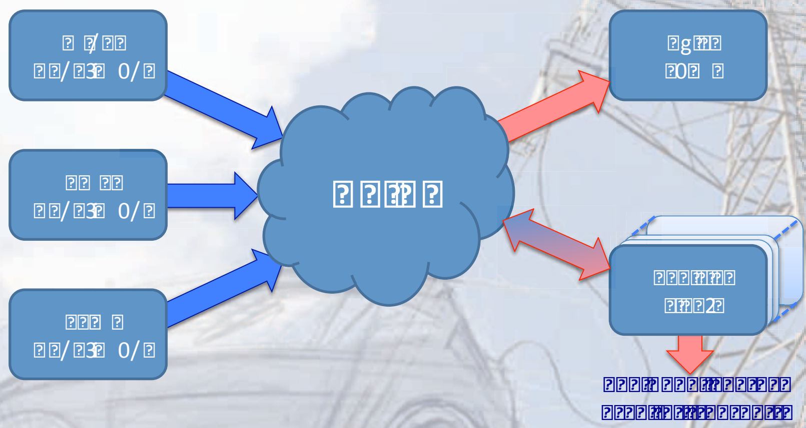
New Zealand energy strategy

- Target 90% renewable electricity by 2025
- For wind alone, this needs 400% increase in contribution
- Current 4% wind contribution only 1/3 of capacity of installed turbines
- Other drivers for growth of renewables:
  - increasing demands for electricity
  - reducing dependency on fossil fuels
  - greenhouse gas to 80% of 1990 levels by 2020
  - encouraging alternative transport fuels and EVs

Renewable integration issues for NZ

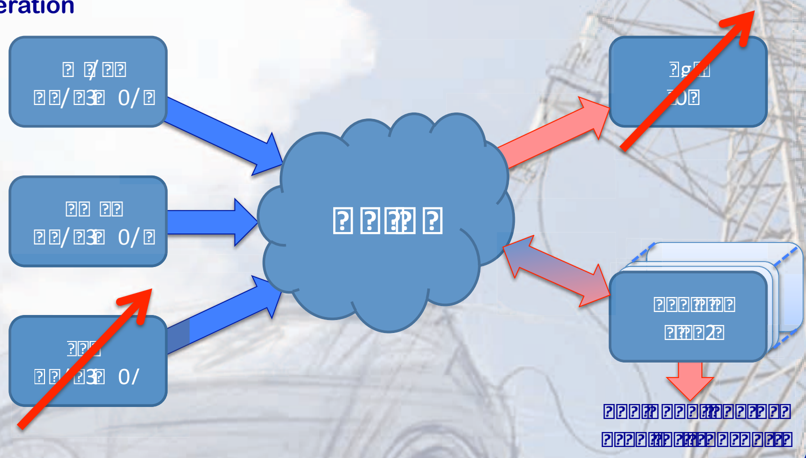
- High proportion of existing renewable energy
- Relatively small and stand-alone grid
- Simple government and regulatory environment
- Record as test-bed for nation-wide systems (eg banking)

Simulation overview



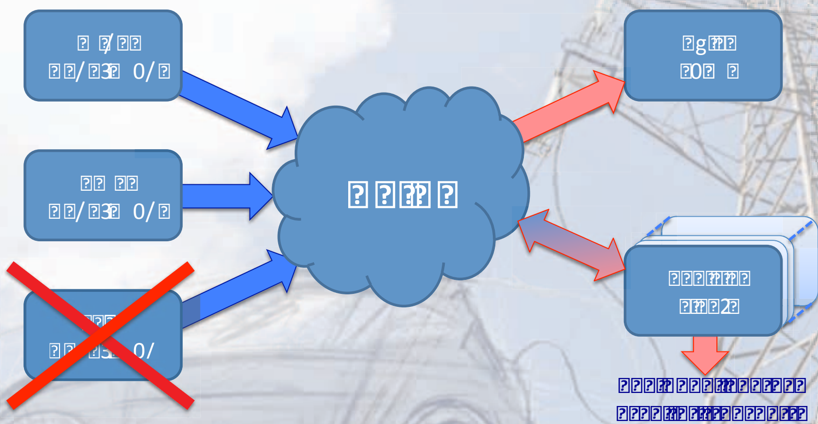
Simulation overview

Peak generation varied to match load and shortfall in wind and base generation

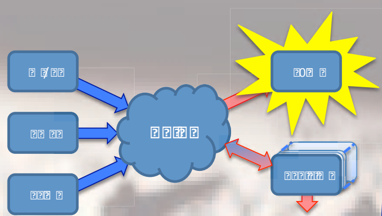


Simulation overview

Ideal is to be able to remove need for peak generation



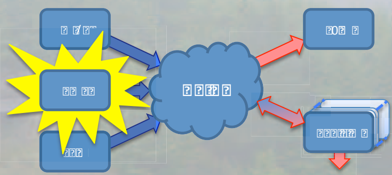
Bulk load

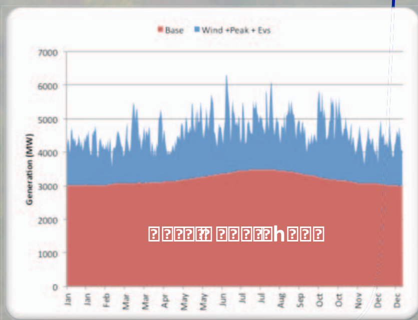


- Have real zone-load data from the transmission network operator
- Covers entire grid
- 5 minute intervals over a whole year

Base generation

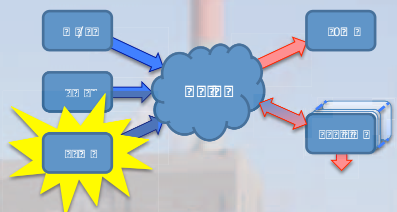
- Calculated as a fraction of average demand (including EVs) with 3 month sliding window
- Fraction determined by % wind penetration
- In reality a mix of generation types – hydro, geothermal, etc
- Does not attempt to follow load, just seasonal variation



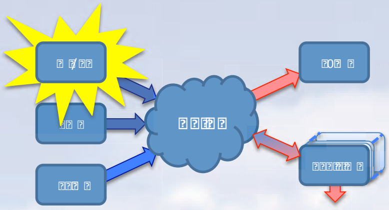


Peak generation

- Fills shortfall between other generation and load
- Generators must be highly responsive
- Need for peak generation shows inefficiency
- In this simulation, the required peak generation at any instant is output data rather than input data

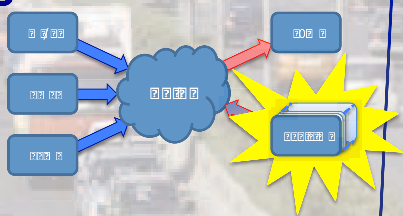


Wind generation



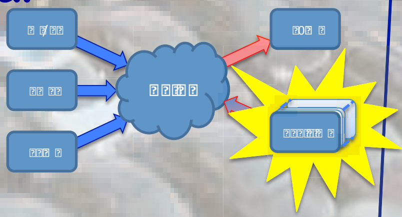
- Dataset of wind speed at 10 minute intervals for current and planned wind farm sites over several years
- All 17 sites aggregated to form one large wind farm, and single wind energy value at each time interval

New Zealand vehicle use



- 4.4M population
- 2.6M light passenger vehicles
- These are 78% of all road vehicles, and are basis for simulation
- Average vehicle use 3.3% over year
- Average distance per day 28Km over 3 journeys

New Zealand EV potential



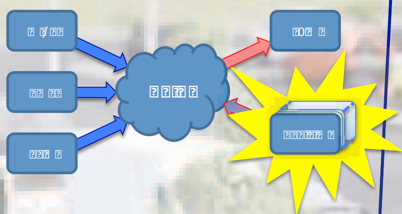
- Typical present-day EV:
  - Range ~150–160 km
  - 16–24 kWh battery
- Assume 1M EVs (40% of fleet)
  - 50 kWh battery
  - only 3.3% in use at any time

    ➔48 GWh of storage
  - could supply peak load for 3 hours

THE UNIVERSITY OF WAIKATO

ENERGY 2013 Lisboa 41

New Zealand EV uptake



- NZ has aging car fleet
  - average age 12.5 years
  - terminal distance 195,000km
- Current retirement/replacement rate would take 17 years to renew entire fleet
- Current uptake of EVs is low (no incentives)
- Estimates suggest 1M EVs by 2040 is realistic (even without incentives)

THE UNIVERSITY OF WAIKATO

ENERGY 2013 Lisboa 42

Electric vehicle simulation model

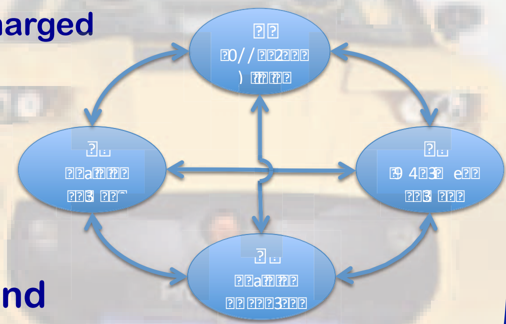
- Two parts to the vehicle model used in the simulation:
  - electrical model – determines charge/discharge decisions when vehicle connected to the grid
  - behaviour model – controls timing and energy use of journeys

Electrical model

- Basic physical parameters can be set separately for each vehicle.
- When connected to grid, each EV makes own decision about charging, discharging or remaining idle (*decentralised smart charging*)
- Naïve protocols might charge at maximum rate until full, or at minimum rate to meet the requirements of the next trip

Electrical model (2)

- We use a cooperative four-state model controlled by three boolean parameters:
  - F – vehicle fully charged
  - N – grid in deficit
  - P – vehicle able to supply grid
- P determined by state of charge, time to next trip, and required charge for next trip

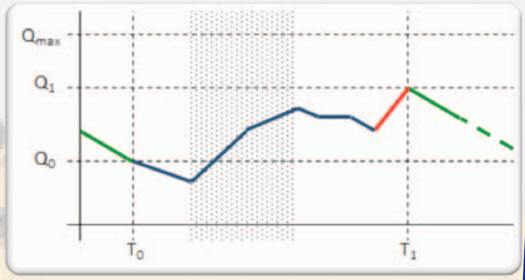


WAIKATO

ENERGY 2013 Lisboa 45

Cooperative charging model

- Charge/discharge as required to balance grid, until charging imperative to reach required charge for next journey.



Grid in surplus; at all other times in deficit or balanced

Charge at maximum rate

Normal driving discharge

Vehicle ends previous journey and connects to grid at time T_0 with charge level Q_0.

Vehicle due to start next journey at time T_1 and requires charge level Q_1 for this journey.

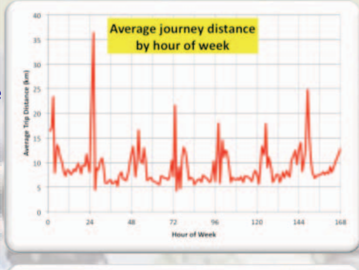
Q_{max} is maximum charge level.

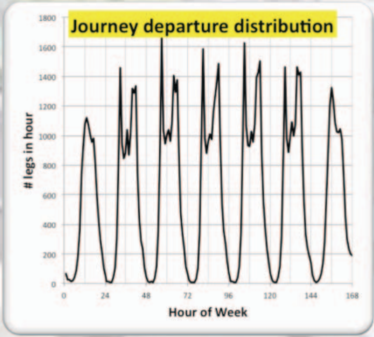
WAIKATO

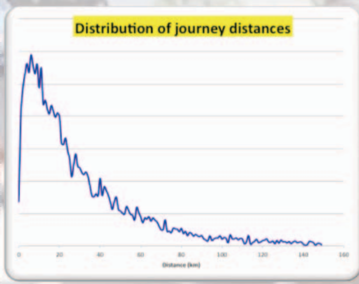
ENERGY 2013 Lisboa 46

Vehicle behaviour

- Each journey specified by a departure time, distance, and average speed
- Journeys derived from this survey data







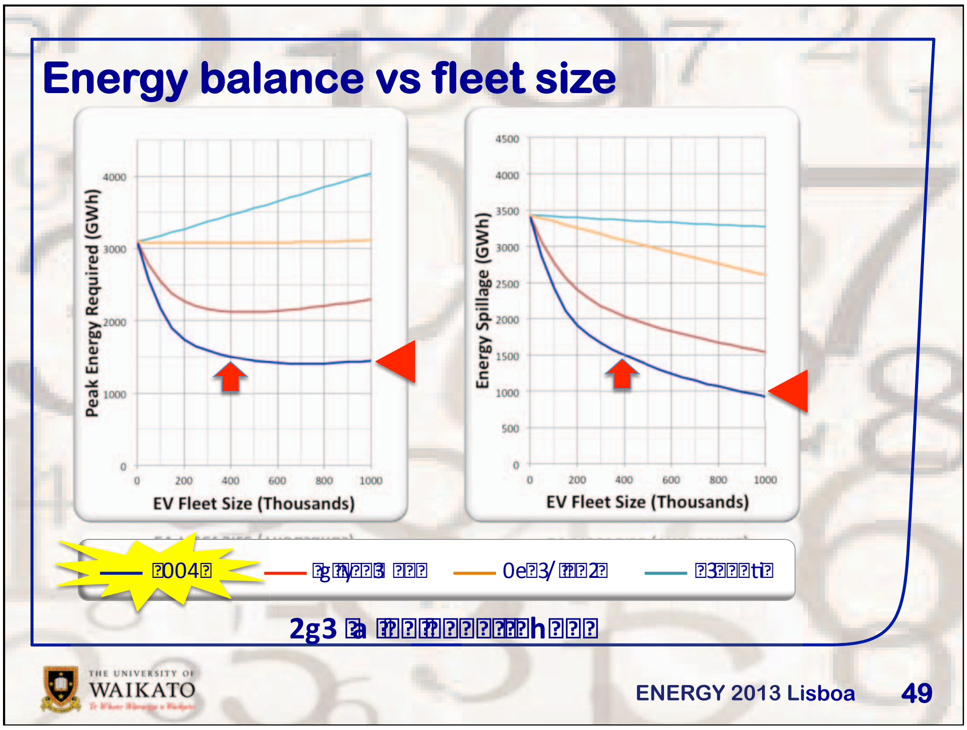
THE UNIVERSITY OF WAIKATO

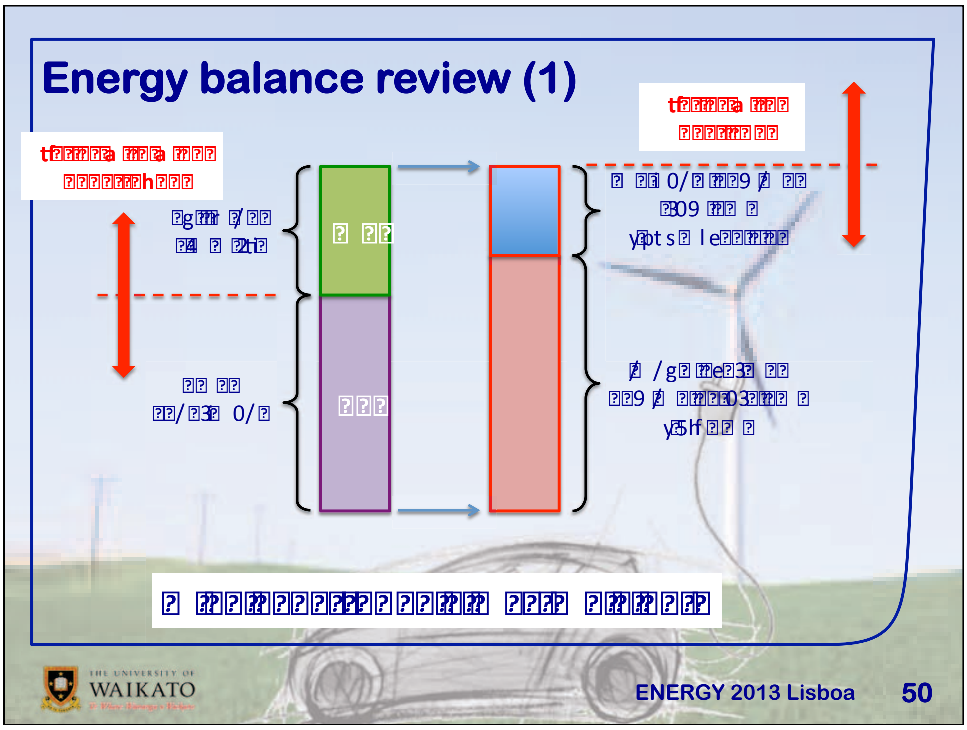
Simulation in operation

At each tick (5 minutes) these steps occur:

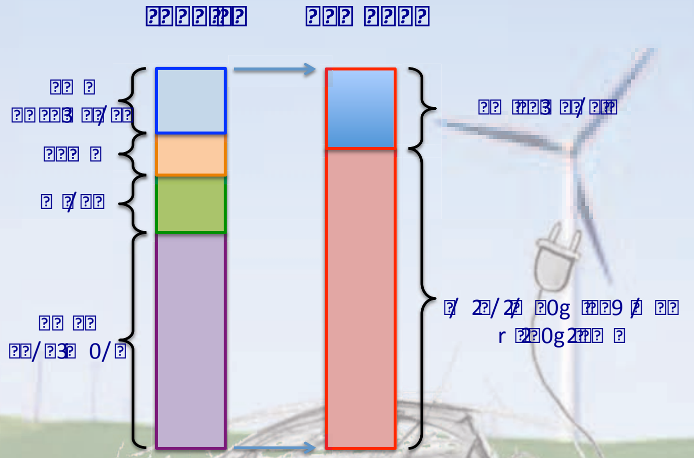
- update vehicle connections (departures and arrivals)
- derive new input values – load, wind, base
- update charge/discharge state for each EV (based on appropriate charging protocol)
- calculate network balance (peak required or wastage)
- record all relevant data for this cycle

THE UNIVERSITY OF WAIKATO


Energy balance vs fleet size
Peak Energy Required (GWh)
EV Fleet Size (Thousands)
Energy Spillage (GWh)
EV Fleet Size (Thousands)
THE UNIVERSITY OF WAIKATO
ENERGY 2013 Lisboa
49

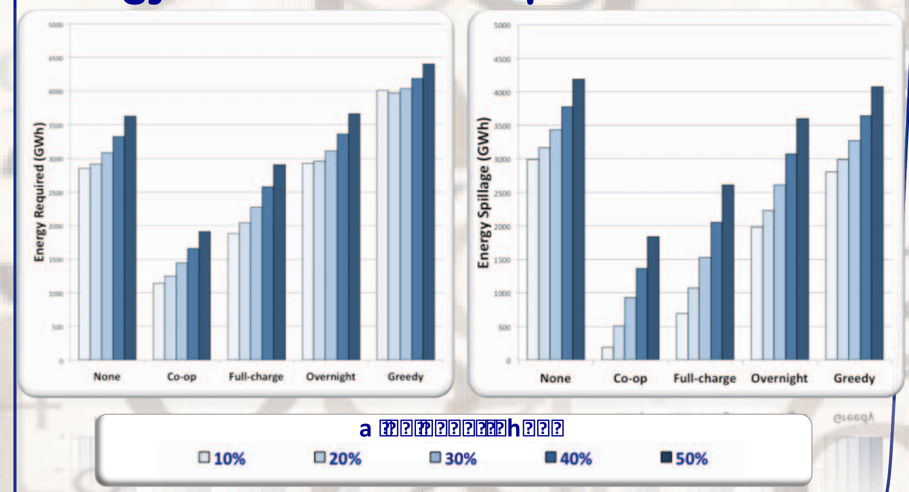

Energy balance review (1)
THE UNIVERSITY OF WAIKATO
ENERGY 2013 Lisboa
50

Energy balance review (2)



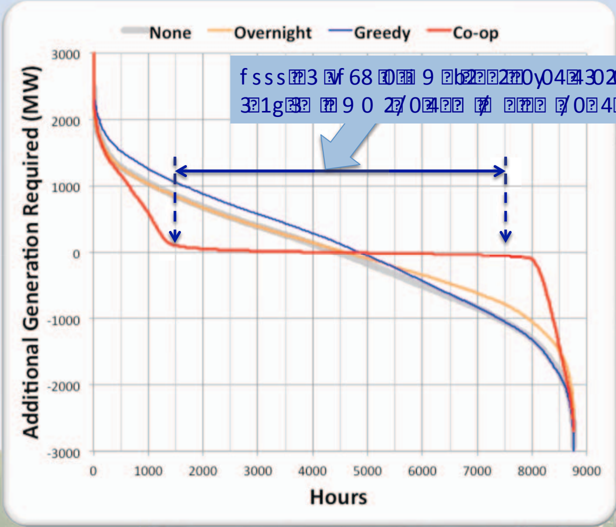
WAIKATO

Energy balance vs wind penetration

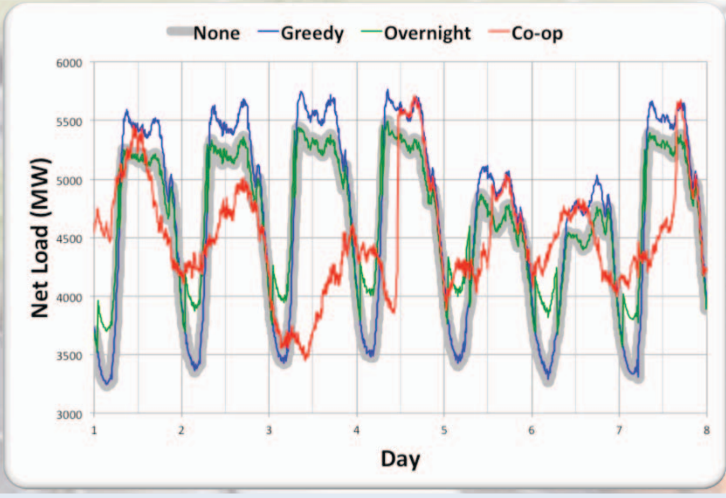


WAIKATO

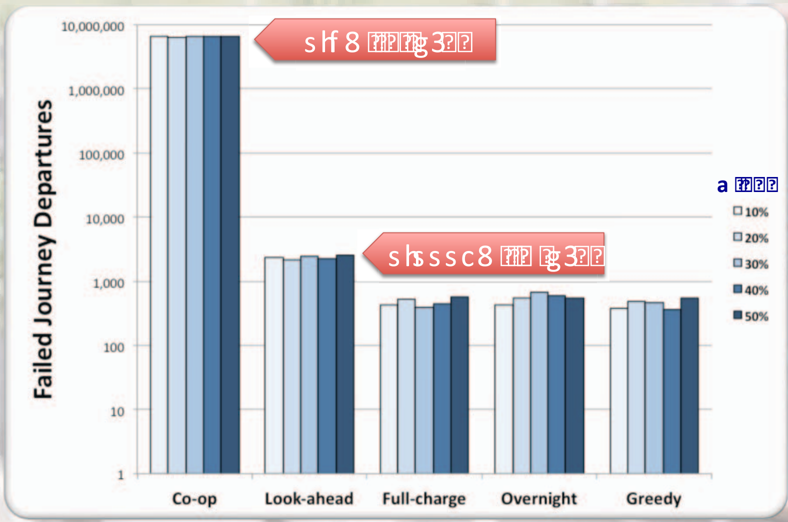
Peak (& spillage) “load” duration



Demand smoothing ?



Failed EV journeys

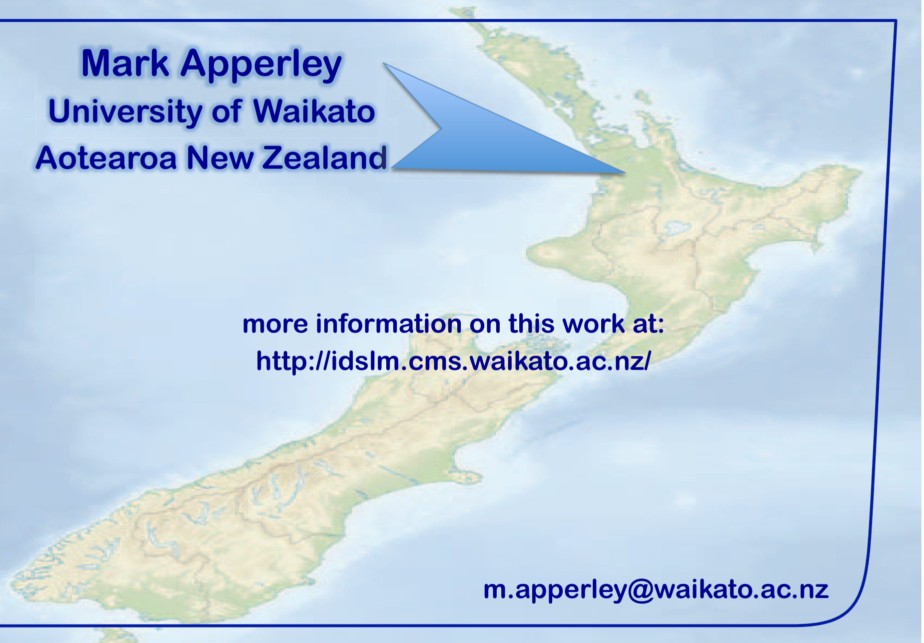


Issues and implications

- V2G can improve renewable integration, but avoidance of back-up investment not established
- Use of back-up significantly reduced suggesting new alternatives
- Spillage significantly reduced suggesting improved efficiency and capacity factors
- Wind penetration of 30% to 50% definitely achievable
- Many advantages with EV uptake at only 12-15%
- Failed journeys could be an issue; better estimates of immediate future use needed

Future work

- Improving estimates of immediate future needs
- More detailed analysis of charge station requirements
- Adding network topology to simulation
- Exploring non-homogenous vehicle mix, including PHEVs
- Charge cycles and battery life implications
- Economic and business models, and “fit” with electricity supply industry
- Individual and society issues



Mark Apperley
University of Waikato
Aotearoa New Zealand

more information on this work at:
http://idslm.cms.waikato.ac.nz/

m.apperley@waikato.ac.nz