


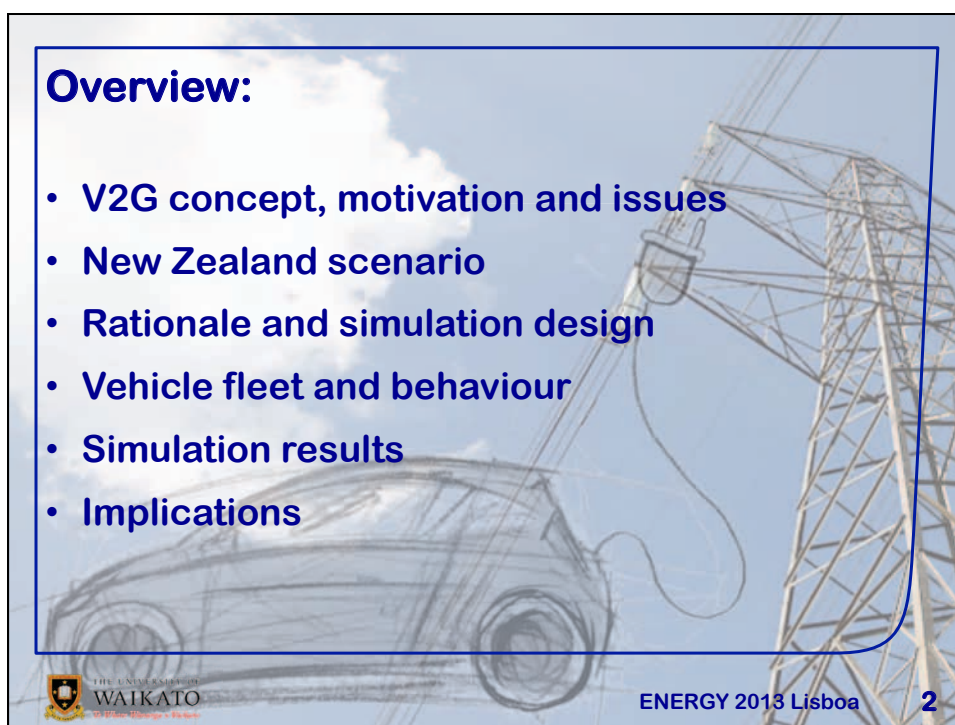
# Electric Vehicles as Grid Storage:

a fine-grained simulation for  
feasibility analysis of V2G

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## Overview:

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

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## Vehicle to Grid (V2G) concept

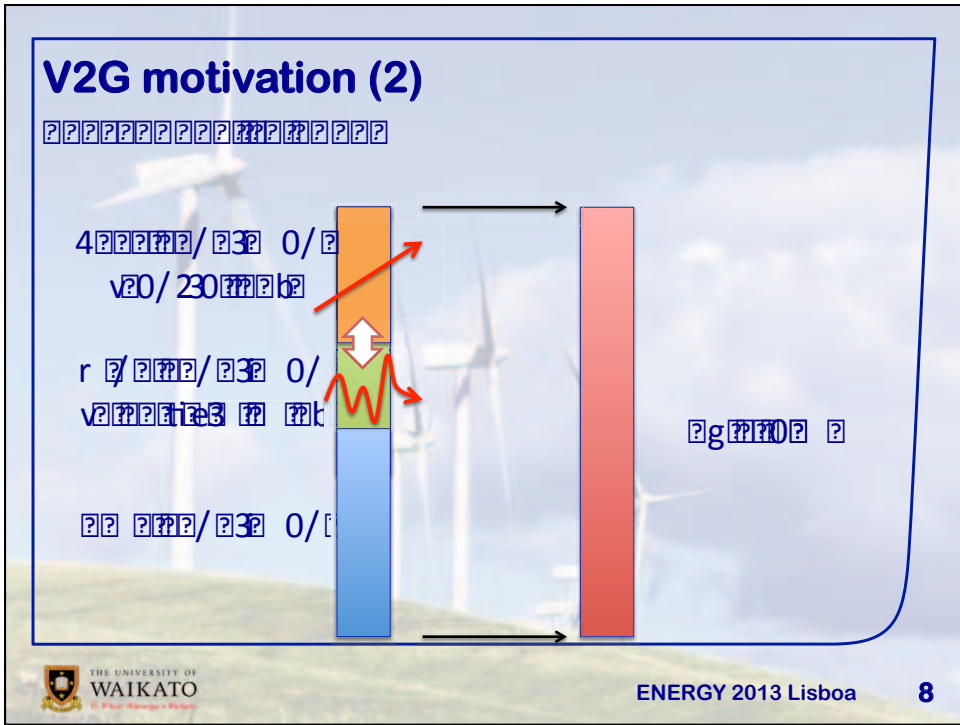
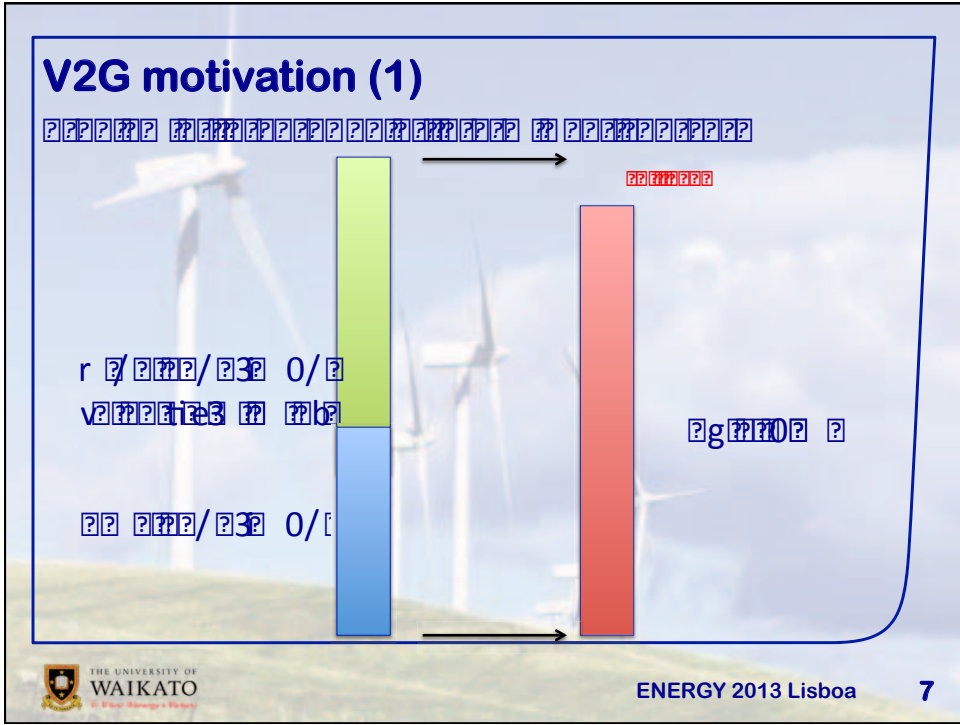
- 1997 Kempton & Letendre reported detailed energy and economic analysis
- When connected to grid, EVs can be treated as both load and source



## 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





### V2G motivation (3)

2 222 2222 2222 22

r 2 2222 / 232 0/2  
v 2222 222 2 222

22 2222 / 232 0/2

2g 2220 2 2

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### V2G motivation (3)

2 222 2222 2222 22

203w 2 2232r / 2  
2309 2 2032222

r 2 2222 / 232 0/2  
v 2222 222 2 222

22 2222 / 232 0/2

2g 2220 2 2

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### V2G motivation (3)

Fig 34 2030

r 0/0  
v

Fig 34 2030

Fig 34 2030

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### V2G motivation (4)

Fig 34 2030

r 0/0  
v

Fig 34 2030

Fig 34 2030

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### V2G motivation (4)

$\frac{0.3 \text{ MWh}}{0.09} = 3.33 \text{ r / kWh}$   
 $\frac{0.09}{0.03} = 3$   
 $\frac{0.03}{0.09} = 0.33$   
 $\frac{0.03}{0.09} = 0.33$

Example 1: 100 kWh  
 Example 2: 300 kWh

Example 1: 100 kWh  
 Example 2: 300 kWh

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### V2G motivation (4)

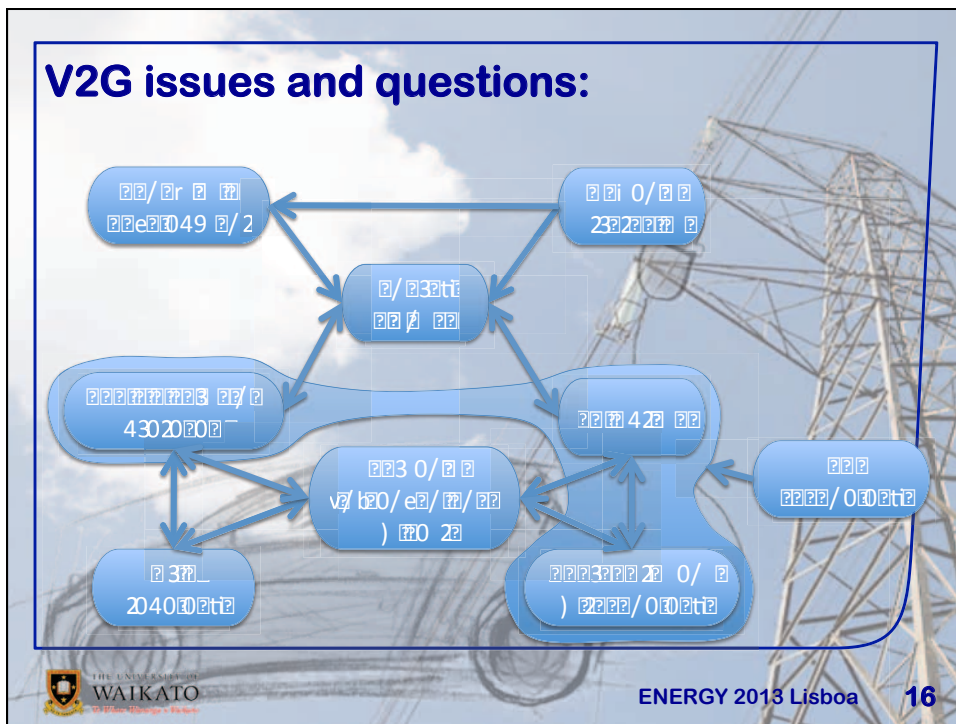
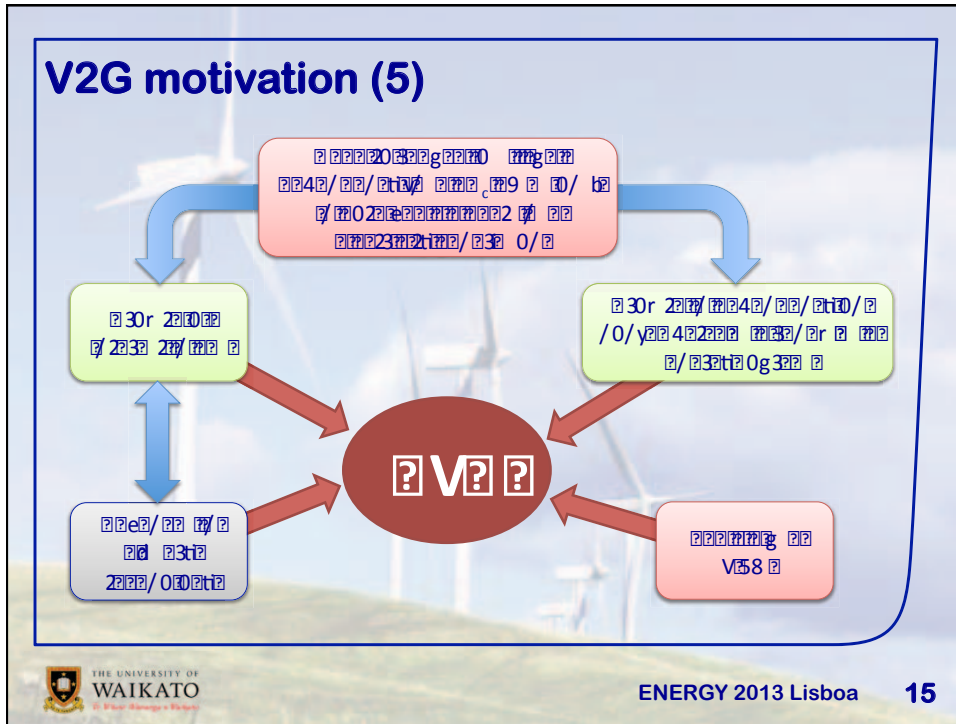
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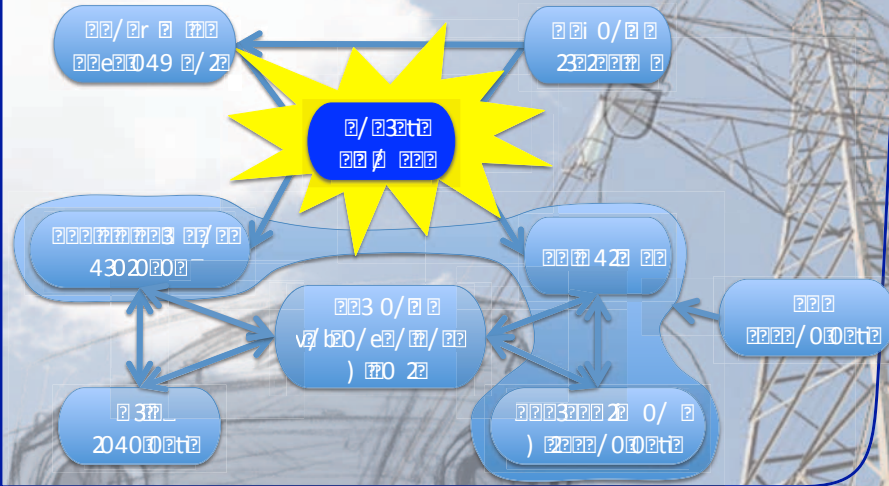
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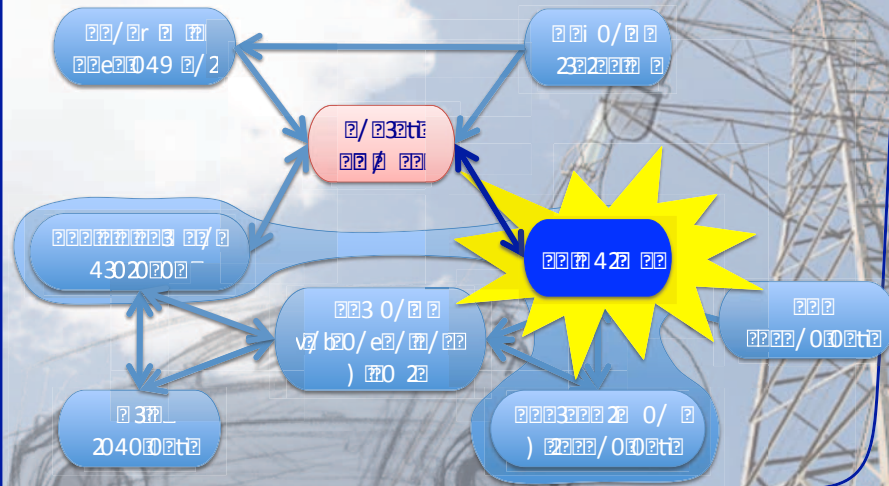




1. Can overall energy balance be maintained in real-time minimising peak generation requirements?



2. Is the uptake of electric vehicles likely to be sufficient to ensure V2G's viability?



### 3. Vehicle charging and control protocols and smart-grid integration are critical to the success of V2G

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### 4. Where vehicles are charged and the charging technology are detail issues, but highly relevant

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**5. At-home connection has significant implications for distribution networks and bi-directional flows**

The diagram illustrates a distribution network with several nodes and bidirectional connections. A central node, highlighted with a yellow starburst, is labeled '2040000000'. It is connected to a node labeled '4302000000' on the left and '2222420000' on the right. Above these are nodes '2222490000' and '2322222000'. Below the central node is a node labeled '2000000000'. The background features a high-voltage power line tower.

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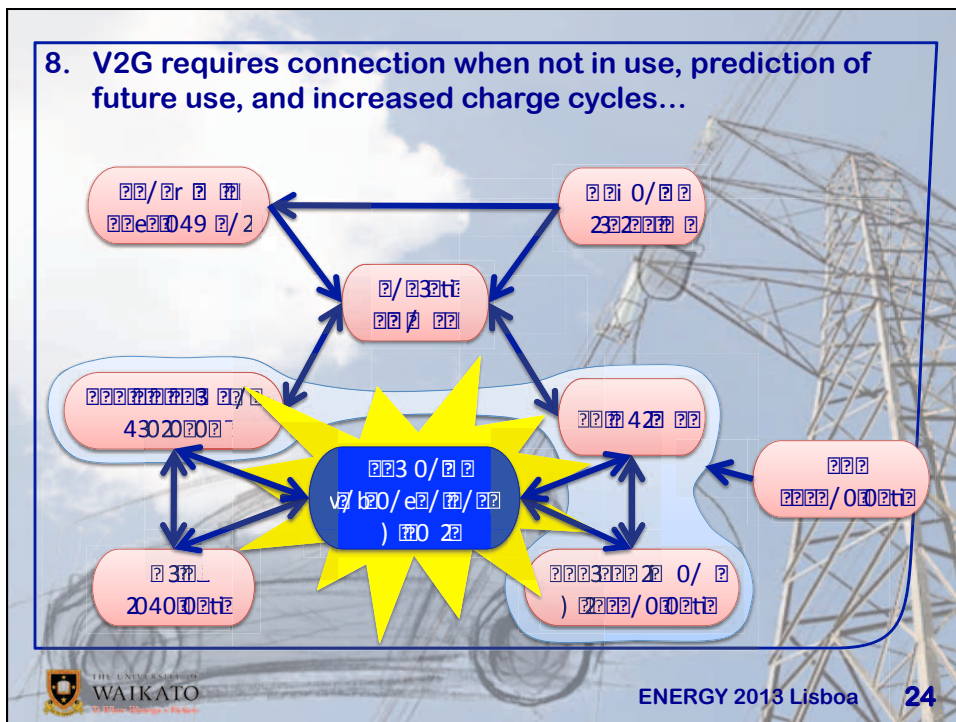
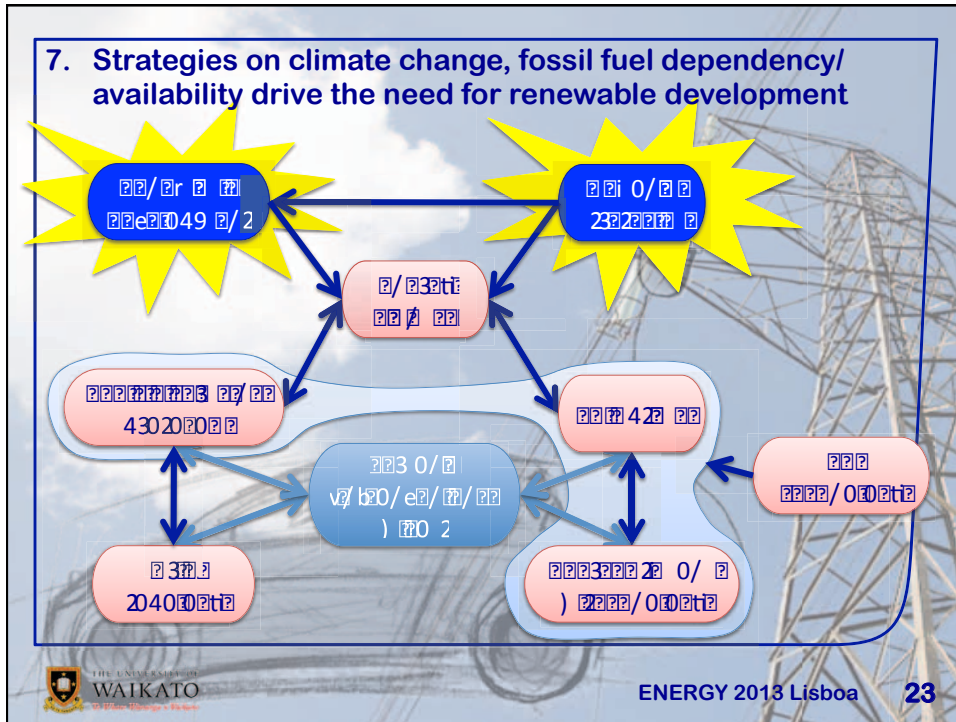
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**6. Advances in EV technology will influence uptake, but also charging protocols, technology and usage patterns**

This diagram is identical to the one on slide 21, showing a distribution network with bidirectional flows. In this version, the yellow starburst highlights a node on the right side of the network, labeled '2000000000'. The background features a high-voltage power line tower.

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

The diagram illustrates the V2G ecosystem with the following components and relationships:

- Electricity Retailer** (top left) and **Electricity Supplier** (top right) are connected to the **Electricity Distributor** (center).
- The **Electricity Distributor** is connected to the **Electricity Consumer** (middle left) and the **Electricity Producer** (middle right).
- The **Electricity Consumer** is connected to the **Electricity Storage** (bottom left) and the **Electricity Network** (bottom center).
- The **Electricity Producer** is connected to the **Electricity Network** and the **Electricity Vehicle** (bottom right).
- The **Electricity Storage** and **Electricity Network** are connected to the **Electricity Vehicle**.
- A large yellow starburst points to the **Electricity Retailer** node.

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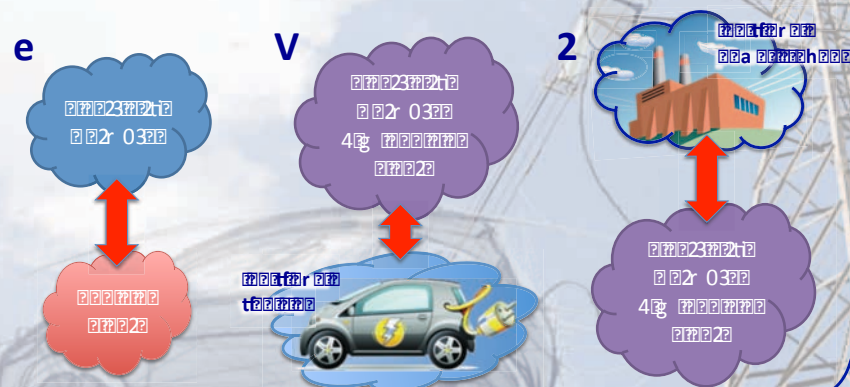
### What is already known about V2G?

- 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

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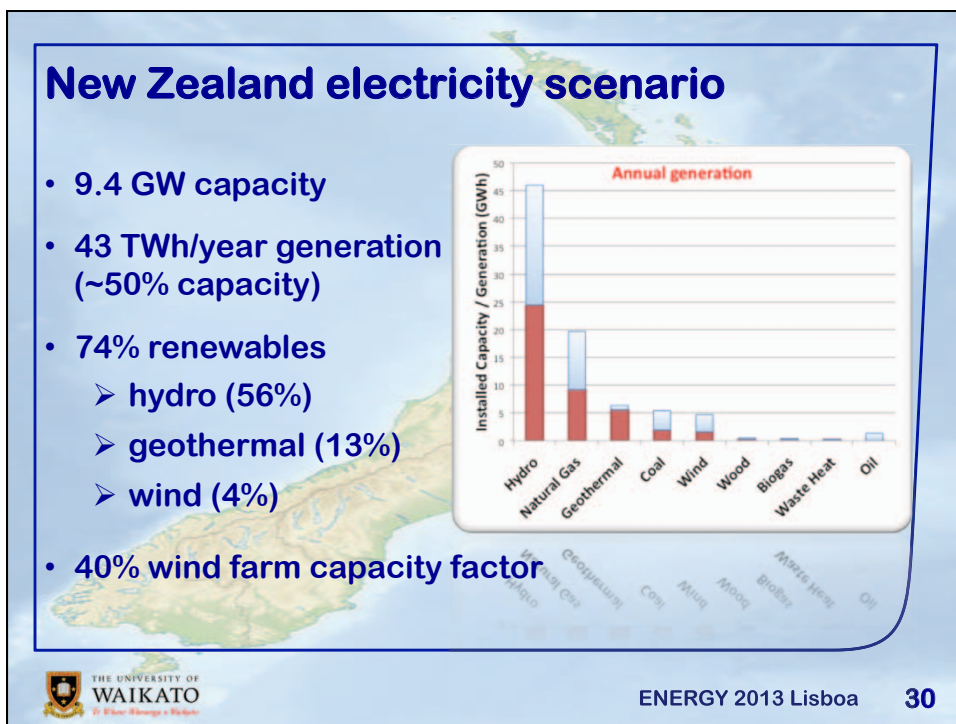
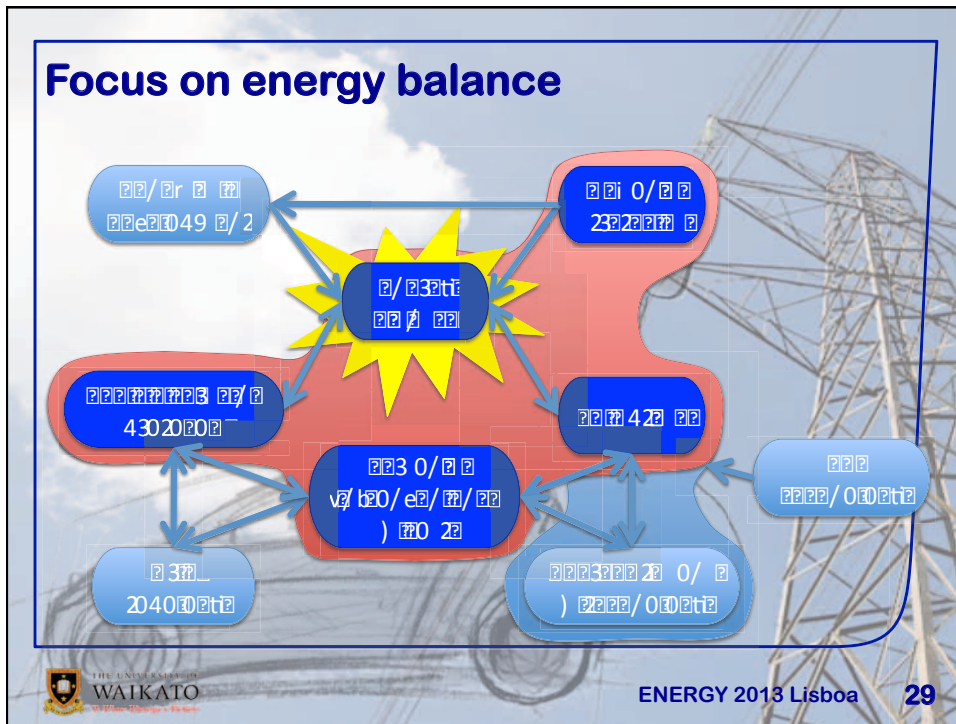
## What is already known about V2G?

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



## 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



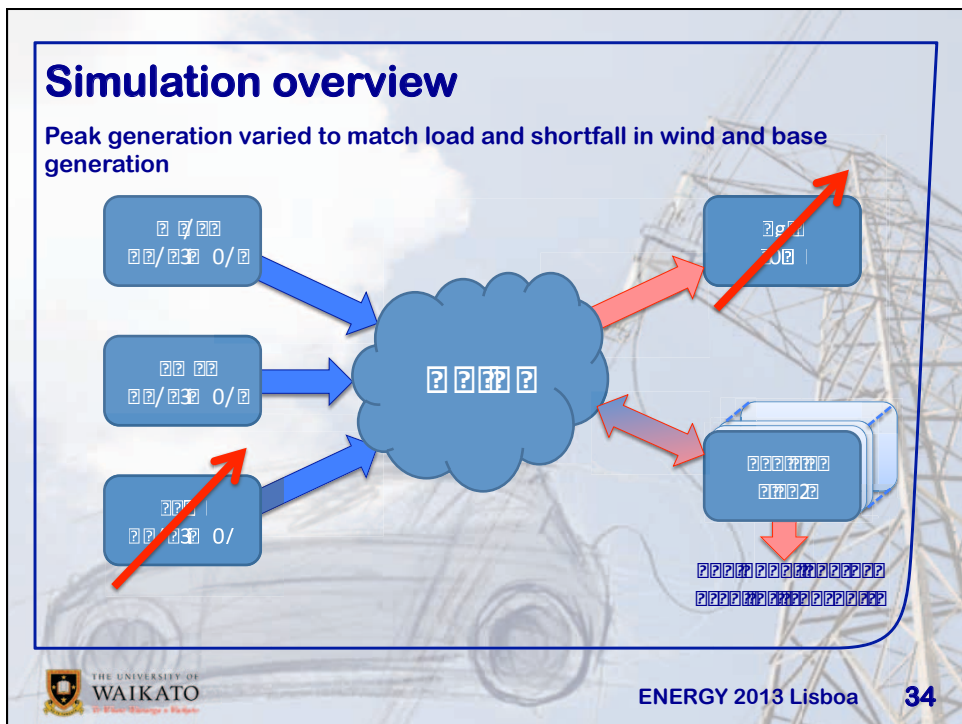
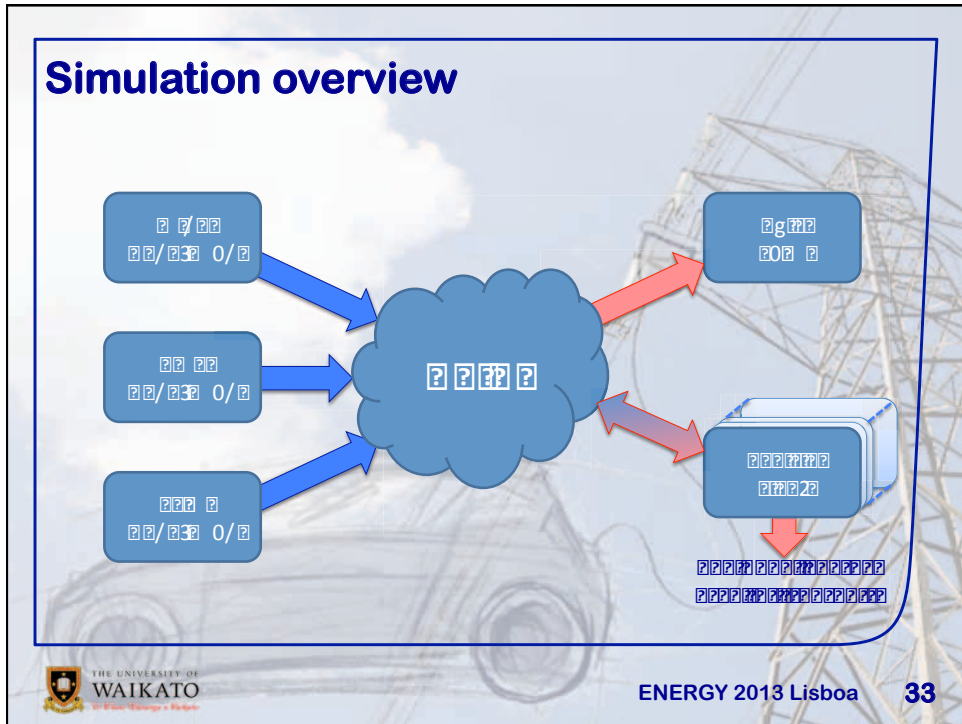
## New Zealand energy strategy

- 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

Ideal is to be able to remove need for peak generation

The diagram illustrates a simulation overview. A central cloud contains four question marks. Four boxes are connected to the cloud: two on the left with blue arrows pointing towards the cloud, one on the left with a red 'X' over it, and two on the right with red arrows pointing away from the cloud. The background features a power line tower and a car.

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### Bulk load

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

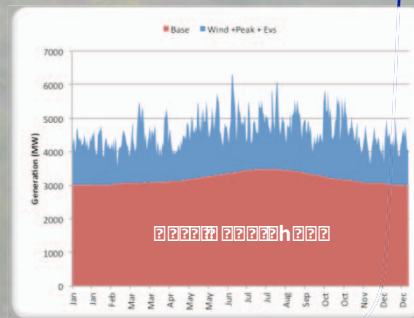
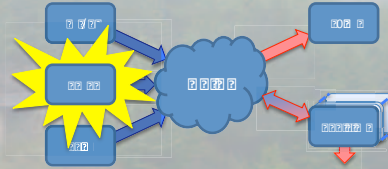
The diagram shows a central cloud with three boxes on the left and two boxes on the right. A yellow starburst is positioned above the top-right box. Blue arrows point from the left boxes to the cloud, and red arrows point from the cloud to the right boxes.

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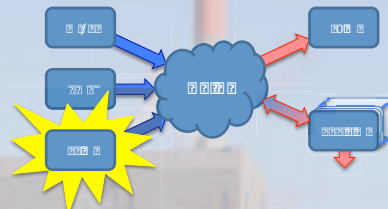
## Base generation

- 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



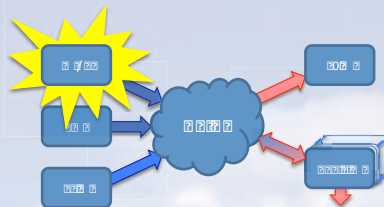
## Peak generation

- 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



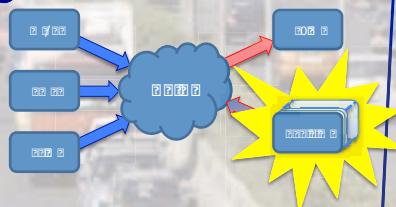
## Wind generation

- 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



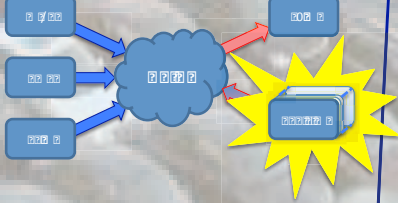
## New Zealand vehicle use

- 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



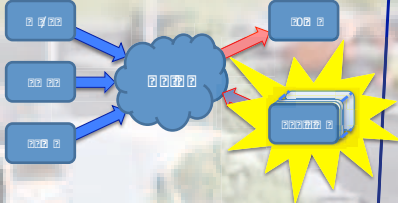
The diagram illustrates a network of three electric vehicles (EVs) on the left, each represented by a blue car icon with a battery symbol. Blue arrows point from these EVs to a central blue cloud icon. From the cloud, a red arrow points to a battery storage unit on the right, which is depicted as a blue battery pack with a yellow starburst effect behind it, indicating energy storage or distribution.

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## 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 diagram is identical to the one on slide 41, showing three EVs connected to a central cloud, which is then connected to a battery storage unit.

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## Electric vehicle simulation model

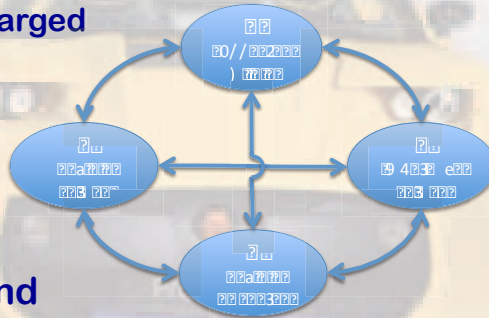
- Two parts to the vehicle model used in the simulation:
  - electrical model – determines charge/discharge decisions when vehicle connected to the grid
  - behaviour model – controls timing and energy use of journeys

## 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

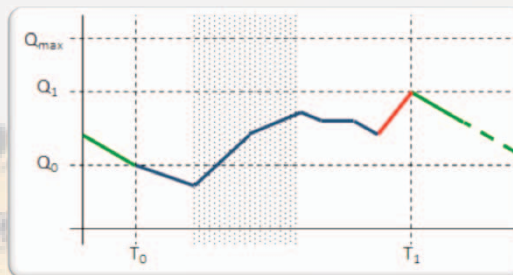
## Electrical model (2)

- 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



## 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

Normal driving discharge

Charge at maximum rate

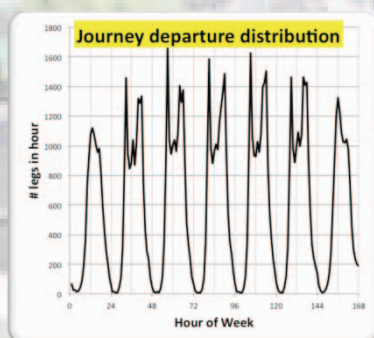
Vehicle ends previous journey and connects to grid at time  $T_0$  with charge level  $Q_0$ .

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.

## Vehicle behaviour

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

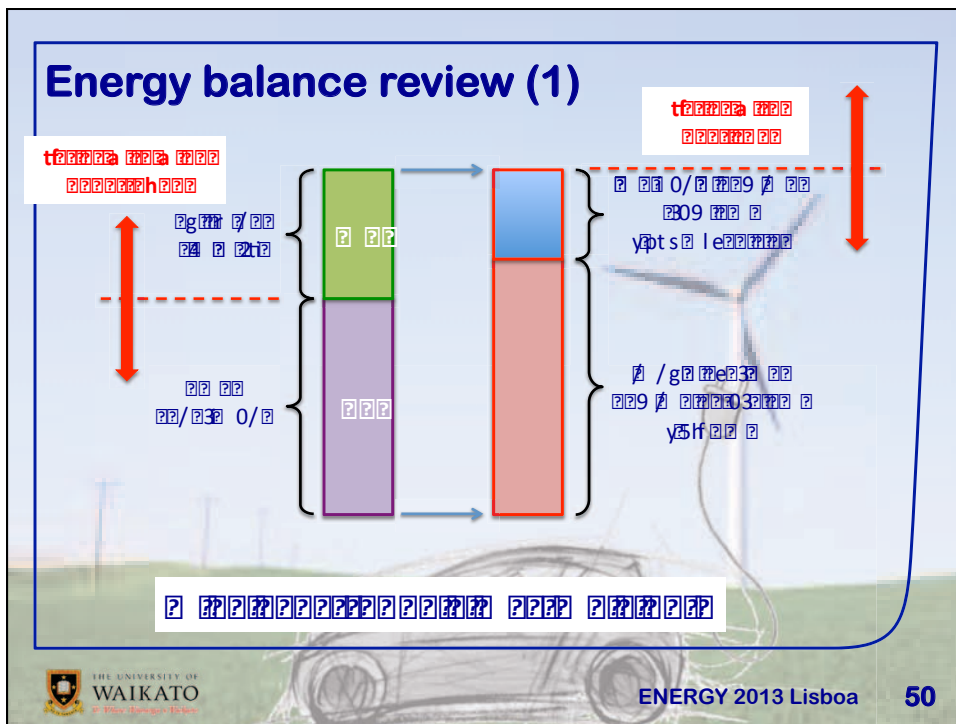
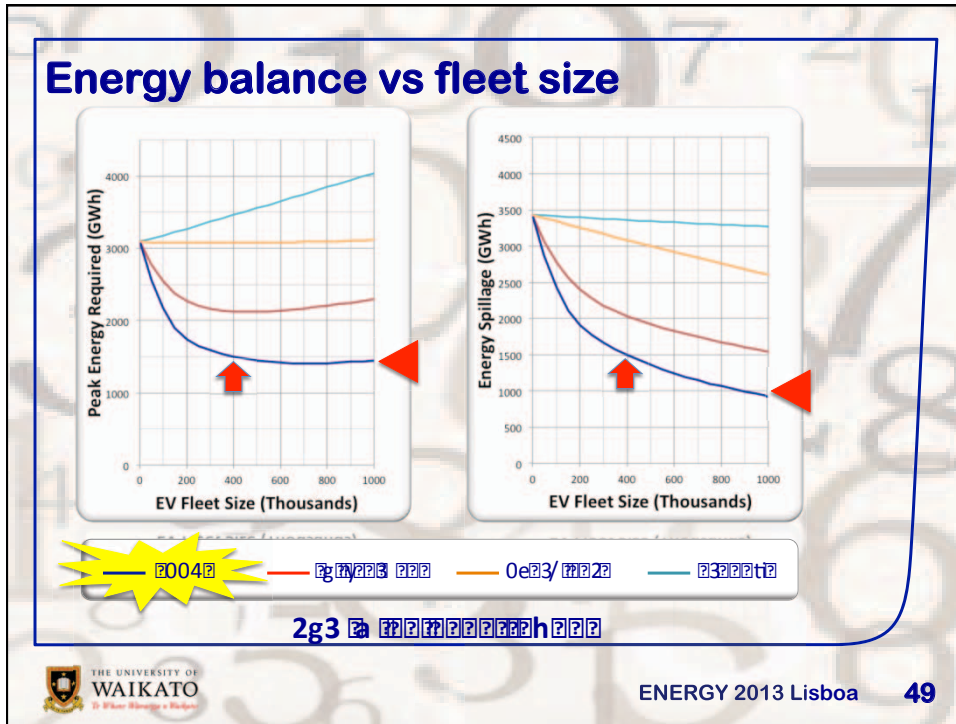


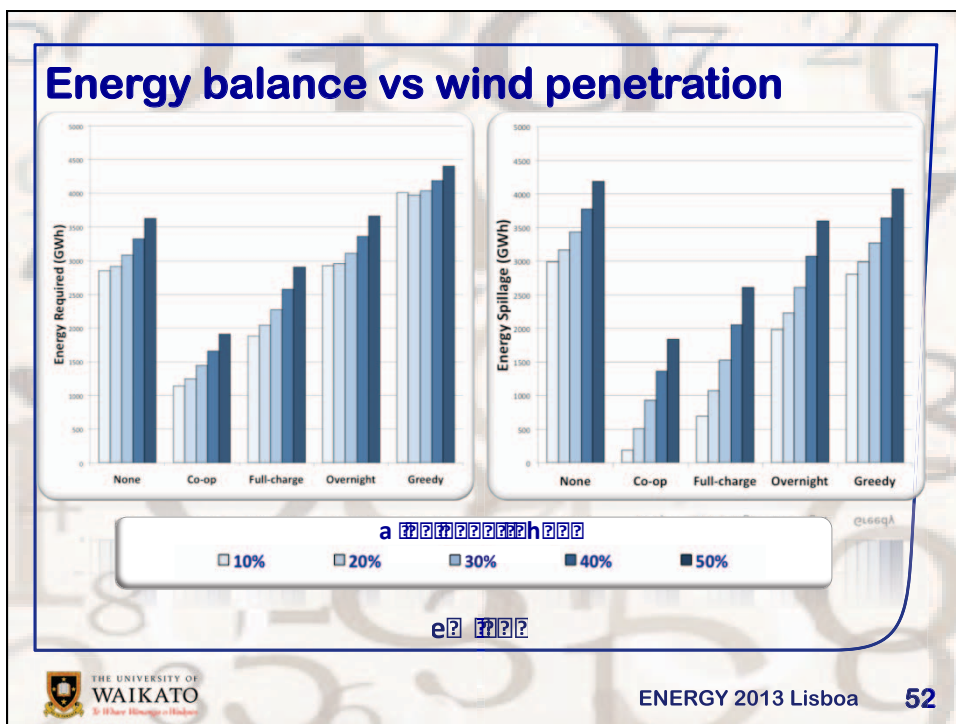
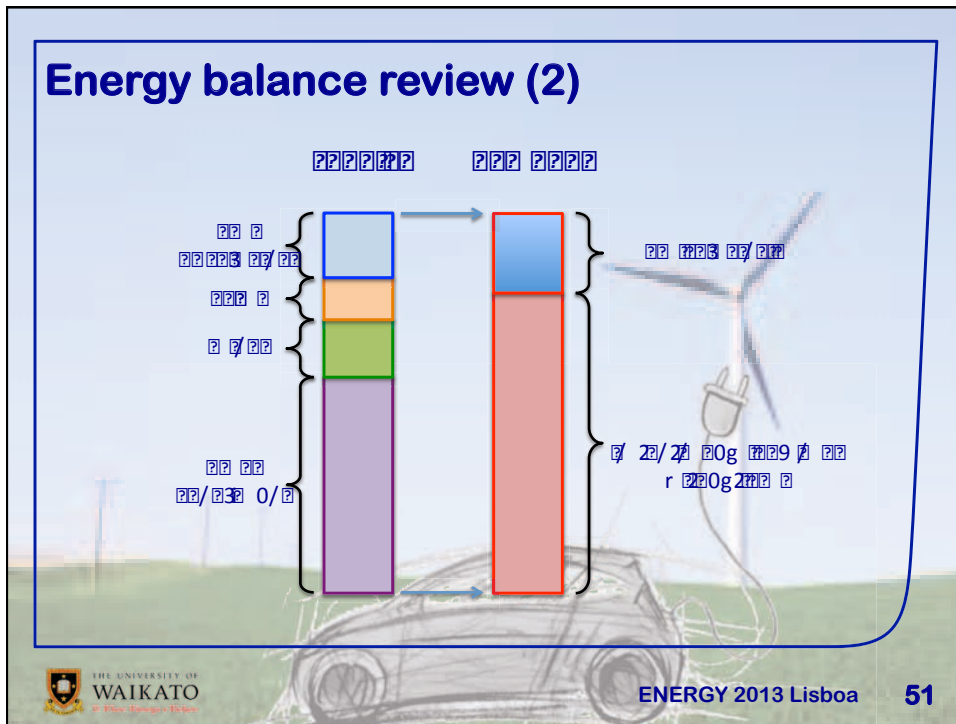
## Simulation in operation

At each tick (5 minutes) these steps occur:

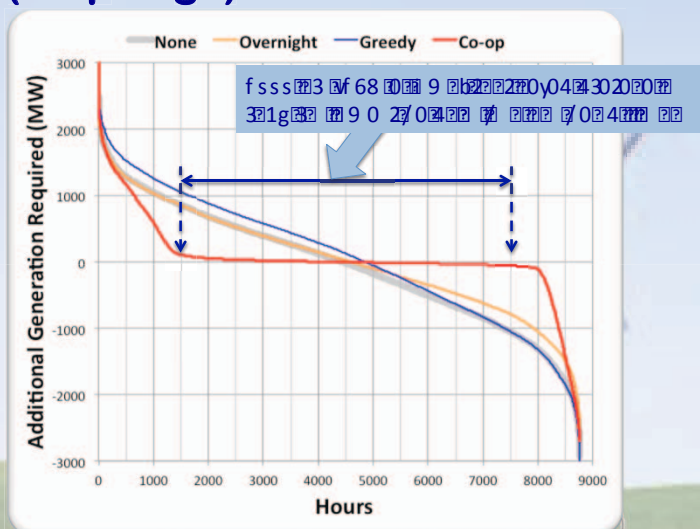
- update vehicle connections (departures and arrivals)
- derive new input values – load, wind, base
- update charge/discharge state for each EV (based on appropriate charging protocol)
- calculate network balance (peak required or wastage)
- record all relevant data for this cycle



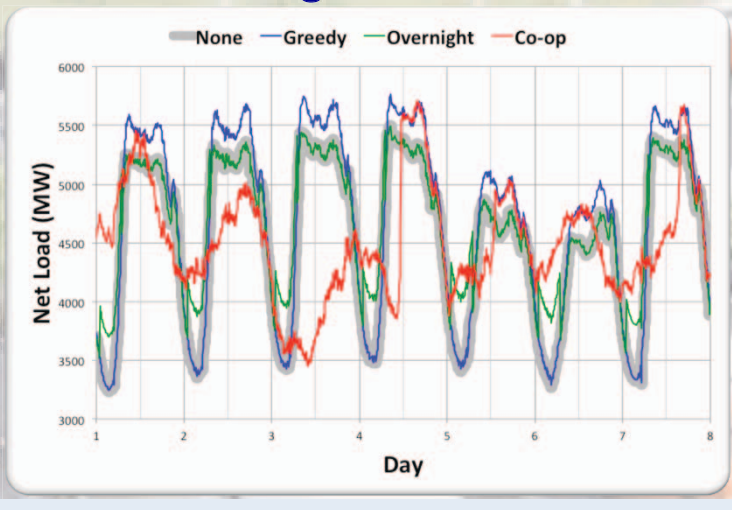




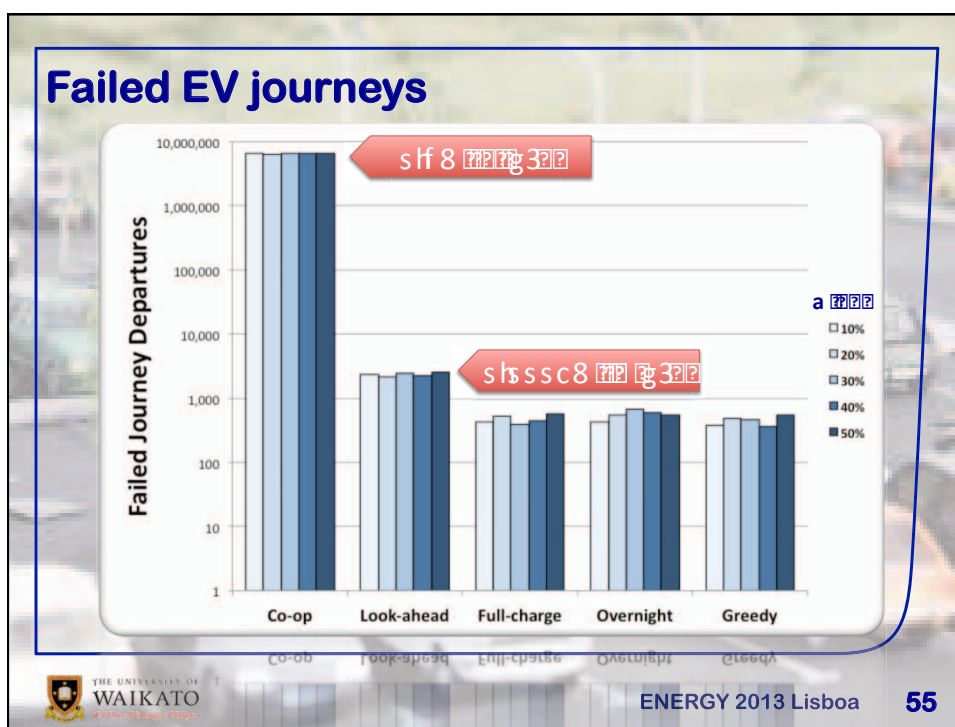
## Peak (& spillage) “load” duration



## Demand smoothing ?



22/04/2009 15:04:36 [4] www.zeuthen.net



- ### 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
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## 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

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