ROBERT GORDON UNIVERSITY•ABERDEEN

Benchmarking electric vehicles

Prof. David Gray
Dr. Bing Xu
Amar Nayak

e-harbours electric

Introduction

- Why are we doing this? (DG)
- Introducing the methodology (AN)
- Comparison criteria and variables (AN)
- Weighting the variables (DG,AN – and you!)
- The model (AN)

e-harbours

- The e-harbours project is interested in smart energy solutions for harbour cities which can help promote renewables
- Looking at energy efficiency and management solutions that can help smooth out the intermittency and balancing problems between demand for energy in harbours and the unpredictable supply of renewable energy
- e-harbours partners are interested in smart grids and virtual power plants

e-harbours and e-mobility

- But we are also interested in Electric and hybrid vehicles and vessels
- Not just as a means of transport or a way to reduce CO2 emissions…
- …but as mobile energy storage and buffering devices

Key questions for e-harbours:

- Can electric and hybrid cars, vans buses, HGVs, cranes, forklifts, hybrid ferries, LNG fuelled barges and even ships themselves become components in smart energy systems?
- Can the smart energy angle make expensive electric and hybrid vehicles more competitive?
- Where are the **business cases**?
- Will there be better business cases associated with some types of vehicles and vessels and not others?

Key questions for Robert Gordon University

- Can RGU develop a **model** to compare and evaluate different electric vehicles and identify those that are well suited to inclusion in a smart energy system…
- … and thus help vehicle and vessel manufactures and policy makers identify and develop business cases around smart energy?

- First – a quick introduction to batteries and energy storage capacity…

Types of Battery

- Lead Acid
- Nickel metal hybrid battery
- Molten salt battery
- Lithium ion battery
- Lithium polymer battery

Battery terms

Specific Energy: Energy per unit mass. Petrol tank has Sp. Energy of 12 Wh/Kg which is 100 times more than best battery. Range of vehicle is fn of Sp. Energy

Specific power: Also known as power density or power per unit volume. Specific power of petrol and battery vehicle is comparable. Sp. Power is important in HEV

Energy density: Amount of energy stored in given system per unit mass. Electric cars need to be as light weight as possible and batteries that are smaller and use less materials can also be lower in cost.

Battery capacity – a comparison

Vehicle	Battery capacity
Chevrolet Volt (Small car)	16 kWh
Tesla Model S (Mid car)	40 kWh
BYD E6 (Van)	48 kWh
BYD E9 (Bus)	100 kWh
Electric Drayage Trucks (Massive truck)	235 kWh

Current battery price $500 to $600 per kWh

RGU methodology

- Comparing different types of electric (and hybrid) 'harbour' vehicles and vessels (cars, buses, HGVs, cranes, forklifts,
- Vehicles are usually compared on a ,limited number of criteria - cost, emissions, etc.
- Poor business case for electric vehicles based on lifetime cost
- Are there better business cases around including electric vehicles in smart energy systems (Malmo's smart houses!)
- If so – what **wider criteria** should we compare different vehicles on?

RGU methodology

Thinking about electric and hybrid vehicles as part of smart energy systems:

- What **wider criteria** should we compare vehicles on?
- What **variables** should be included to represent that criteria?
- What **weighting** should be attached to these variables (this is where *you* come in)?
- Can we get data for all the variables?

- Some data is readily available…

Some Available Benchmarking Data

Model	Price ($)	Charge life	Capacity	Max Speed
Tesla S	57400	160m	40 KWh	110mph
Nissan leaf	30,990	100m	24 KWh	90mph
Ford Focus	39,200	76m	23 KWh	85mph
Chev. Volt	34995	50m	16 KWh	99mph
BMW Mega city	40,000	100m	22 KWh	94mph
Coda	38,145	125m	31 KWh	85mph
Blue Zero E cell	NA	124m	35 KWh	94mph
Toyota Prius	$28,245	14.3m	4.4 KWh	111mph
BYD E6	$35,000	186m	48 kWh	100mph

Some Available Benchmarking Data (Contd)

Model	Price	Charge life	Capacity	Max Speed
Mitsubishi iMiEV	29,100	62m	16 KWh	81mph
Bolloré Bluecar	30,000	160m	30 kWh	81mph
Renault Fluence Z.E.	27,300	115m	22kWh	84mph
Subaru R1e	17,500	50m	DNA	65mph
Mitshubishi Outlander	30,000+	35m	12KwH	75mph
Electric Drayage Trucks	208,500	50m	235kWh	40mph
Forklift		6 hrs		10mph
Siemens earth Movers	234,000	AC cont	NA	
Ferries				

Comparing vehicles – important variables?

Variables	Data 'to hand'
Price of vehicle	√
Range of vehicle between recharges	√
Energy Capacity (kWh)	√
Recharge time (if applicable)	√
Maximum Speed (comparative performance)	√
Lifetime 'full cost of ownership' *differential* vs. diesel or petrol equivalent	X
Predictability of use (regular recharging window)	X
Cost of support infrastructure	X
Market Potential (individual vehicles and clusters)	X
Ease of up scaling and lead in time (legislative barriers, contracting, infrastructure funding)	X
What have we missed? ……	?

RGU methodology

Thinking about electric and hybrid vehicles as smart energy systems:

- What **criteria?**
- What **variables** should be included to represent that criteria?
- What **weighting** should be attached to these variables (this is where *you* come in)?
- We want **you** attach a weight to these variables
- We will use your aggregate weightings to weight the variables in our model
- You are participating in the research!

Audience participation – weighting variables

- We will provide a hand out
- We want you to score the ten variables in terms of their importance…
- …so give the **highest score** to the variable which is **most important** for comparing vehicles (in terms of their ability to be part of a smart energy system)
- Score the variables however you like - you can give 0 to a variable if you like
- There is space at the bottom for you to identify and score those variables that you believe are important but that we may have missed
- **Your scores must add up to 100**

Example - Weighting variables

Variables	Score
Price of vehicle	5
Range of vehicle between recharges	10
Energy Capacity (kWh)	15
Recharge time (if applicable)	5
Maximum Speed (comparative performance)	5
Lifetime 'full cost of ownership' *differential*	10
Predictability of use (regular recharging window)	15
Cost of support infrastructure	10
Market Potential (individual vehicles and clusters)	10
Ease of up scaling	10
What have we missed? ……..	5
Must add up to 100	100

PROMETHEE II

- Step 1. Define the preference function

$$P_j(d) = g_j(a) - g_j(b)$$

q / p : a threshold of indifference/strict preference

s : an intermediate value between q & p

Type of Criterion	Formula
1. Usual Criterion	$P(d) = \begin{cases} 0, d \le 0 \\ 1, d \succ 0 \end{cases}$
2. U-Shape Criterion	$P(d) = \begin{cases} 0, d \le q \\ 1, d \succ q \end{cases}$
3. V-Shape Criterion	$P(d) = \begin{cases} 0, d \le q \\ d / p, 0 \le d \le p \\ 1, d \succ q \end{cases}$

PROMETHEE II

Type of Criterion	Formula
4. Level Criterion	$P(d)=\begin{cases}0, & d \le q \\ 0.5, & 0 \le d \le p \\ 1, & d \succ q\end{cases}$
5. V-Shape with indifference Criterion	$P(d)=\begin{cases}0, & d \le q \\ \dfrac{d-q}{p-q}, & 0 \le d \le p \\ 1, & d \succ q\end{cases}$
6. Gaussian Criterion	$P(d)=\begin{cases}0, & d \le 0 \\ 1-e^{-\frac{d^2}{2S}}, & d \succ 0\end{cases}$

PROMETHEE II

- Step 2. Choose weights or relative importance of coefficients of criteria, say w_js (Experts' Opinions)
- Step 3. Compute the preference indices

$$P(\mathrm{a},\mathrm{b}) = \sum_{j=1}^{m} w_j \cdot P_j(\mathrm{a},\mathrm{b}) \Big/ \sum_{j=1}^{m} w_j \; ; \; P(\mathrm{b},\mathrm{a}) = \sum_{j=1}^{m} w_j \cdot P_j(\mathrm{b},\mathrm{a}) \Big/ \sum_{j=1}^{m} w_j$$

where $0 \le P(\mathrm{a},\mathrm{b}) + P(\mathrm{b},\mathrm{a}) \le 1$

- Step 4. Compute Positive, negative & net outranking flows

$$\phi^{+}(a) = \sum_{b \in A \setminus \{a\}} P(a,b); \quad \phi^{-}(a) = \sum_{b \in A \setminus \{a\}} P(b,a); \quad \phi(a) = \phi^{+}(a) - \phi^{-}(a)$$

- Step 5. Define Binary Outranking Relation S:

$$a \; S \; b \Leftrightarrow \phi(a) \ge \phi(b)$$

Questions for the panel (and the audience)

We want some feedback:

- Is this a credible approach?
- Can it work?
- Are there problems that need to be addressed?
- In what ways do we need to refine the approach?
- What other factors need to be considered?
- Panel feedback
- Observations and questions from the audience on the methodology
- Reflections on the event as a whole