Networks and Urban Energy Use

Applications and Methods

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18th October 2012

Contents

Who am I and Why am I here?

Two questions:

1. What have I got to do with networks?
2. What have networks got to do with energy and buildings?

Who am I and Why am I here?

Two questions:

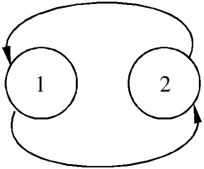
1. What have I got to do with networks?
2. What have networks got to do with energy and buildings?

Career history

1. Ph.D.: Chaos in coupled systems (Manchester). 2003–2007
2. PDRA: Emergence in complex systems (BICS). 2007–2009
3. Research Fellow: Energy and complexity (Leeds). 2010–2012

1. Coupled nonlinear systems [1]

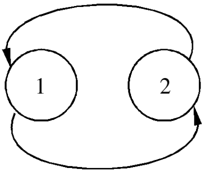
- Simple systems of oscillators: rings & feed-forward networks. . .

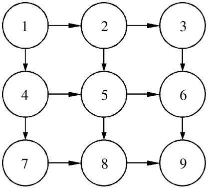


[1] University of Manchester

1. Coupled nonlinear systems [1]

- Simple systems of oscillators: rings & feed-forward networks...
- More complicated arrays.



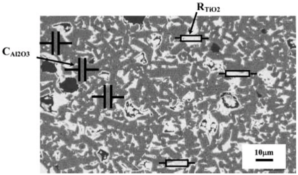


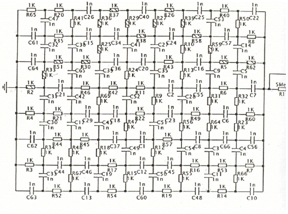
- Application to distributed generation.

[1] University of Manchester

2. Complex network models [2]

Models of composite materials





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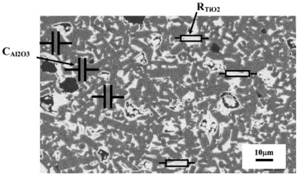

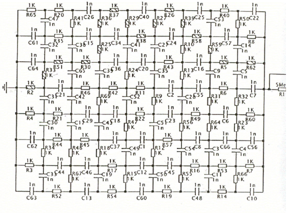

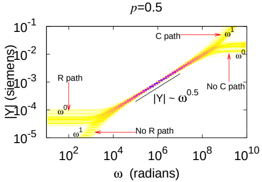

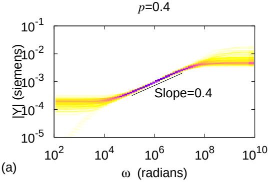

- Explained emergent power-law dependence of conduction on component ratio.
- Applications in materials science...

[2] BICS

Diffusion of Innovation on Networks [3]

Self Introduction

Who am I and Why am I here?

Diffusion of Energy Efficiency Innovation via Social Networks

Social Network Models

Models of Innovation Diffusion

Methods of Analysis

Modelling Inhomogeneity

Real World Scenarios

Future Energy Networks

Domestic Energy Networks

Distributed Generation

Smart Metering

[3] With: C.S.E. Bale, A.M. Rucklidge, T.J. Foxon, W.F. Gale, University of Leeds.

Background

- Energy use is both behaviour and use of technology. . .

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- Decision-making tools are needed to support their potential contribution to energy and climate change targets [1].

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- Quantifying and integrating real-world data into models needs to be addressed.
- We consider diffusion of EE innovations spread by "word of mouth". . . i.e. via interpersonal social network.

Diffusion Models

- Individuals are considered as *nodes* on a network.
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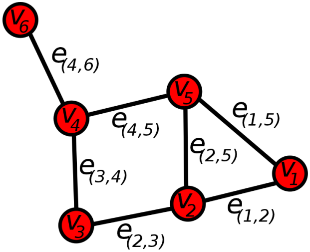

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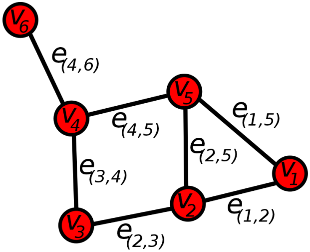

- Contact models (SI &c.): Single contact required for "infection".

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- Uptake based on *"Utility"* crossing a threshold:

$$\text{future state: } x_i' = \begin{cases} 1 & \text{if } x_i = 1, \\ 1 & \text{if } x_i = 0 \text{ and } u_i > \theta_i, \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

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- θ_i: threshold (barriers, costs etc.)
- Network diffusion: proportion of neighbours.

Why is Energy Different?

- Model of uptake of technology.
- E.g. Smart-phones:
  - visible and socially desirable,
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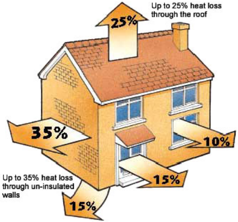
http://www.greendayrenewables.com

Why is Energy Different?

- Model of uptake of technology.
- E.g. Smart-phones:
  - visible and socially desirable,
  - mediated by social contacts between individuals.
- Energy technologies:
  - sometimes visible (solar panels).
  - can be hidden (e.g. loft insulation),
  - decisions based on individual benefit.

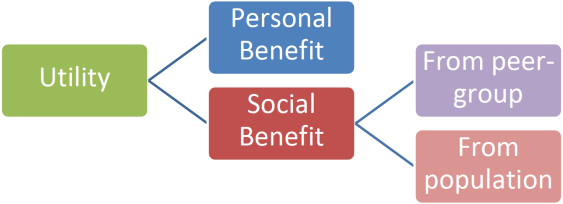
http://www.greendayrenewables.com



http://www.homeinsulationgrants.com

Modelling Uptake of Innovations

- Decision of to adopt based on combination of factors:
  - personal + social benefit [2].



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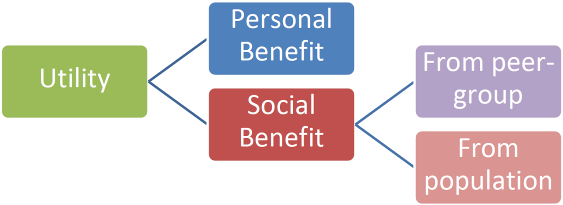
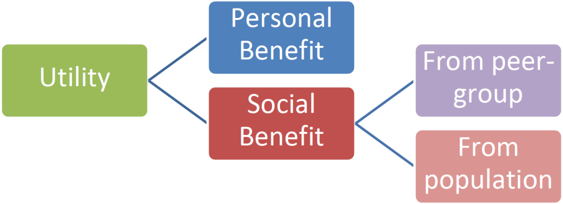


Modelling Uptake of Innovations

- Decision of to adopt based on combination of factors:
  - personal + social benefit [2].
- Intrinsic benefits to individual.
- Social benefit combination of both [5]:
  - personal social network – friends & neighbours,
  - mainstream social norm (society as a whole).



Mathematical Model

- Total *utility* to individual:

$$u_i = \alpha_i p_i + \beta_i s_i + \gamma_i m \quad (2)$$

- p_i, s_i, m: personal, peer-group and societal influence.
- $\alpha_i, \beta_i, \gamma_i$: relative weightings given to each factor,

Real-world social networks

- Real networks have many features, including:
  - local connections, distant ties, wide spread in degrees, community structure. . .

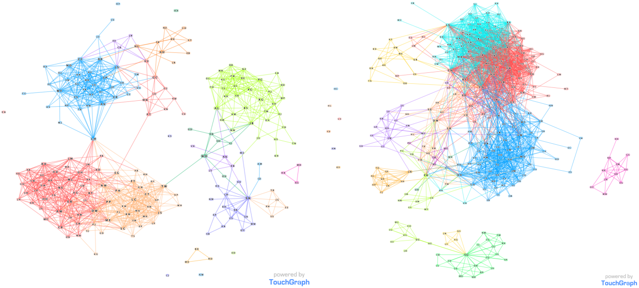
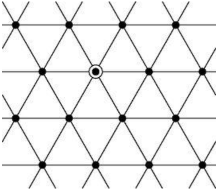


Figure: Inter-friend contacts on the *Facebook* website.

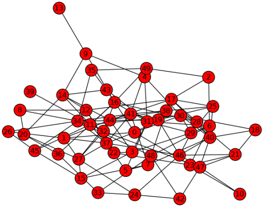
Network models

- Regular lattice:



+ e.g. city-like geography,
+ can have high *clustering*,
- long path-lengths $l \propto d^{1/D}$.

- Random (Erdős Renyí):



+ short path lengths $l \propto \frac{\log N}{\log \bar{k}}$,
- no *clustering* ($N \to \infty$).

"Complex" networks

- Different models reproduce different features.

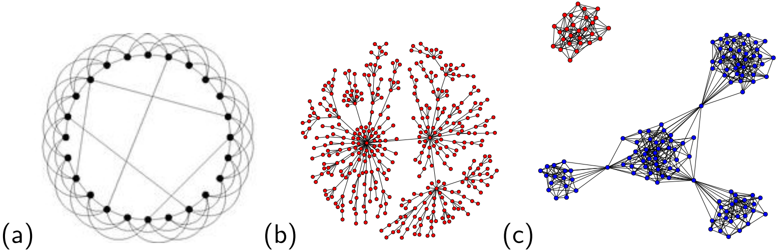
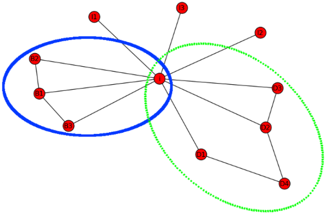


Figure: (a): A *small world* network with random *rewiring* of a regular lattice.
(b): A preferential attachment graph which has a *scale-free* degree distribution.
(c): A simple model of weakly-connected communities.

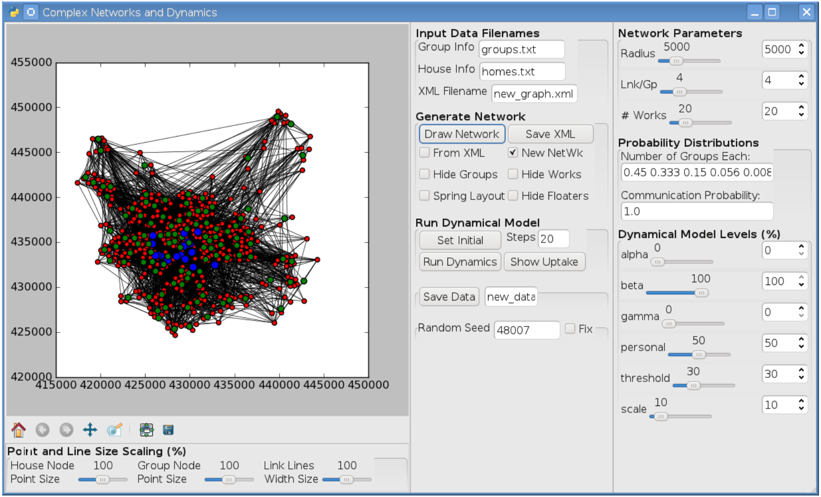
Random Clustered Model [4]

- Each node associated with G *groups*.
- Linked to L others in each group.



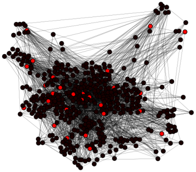
- Can also be linked to individuals in wider network.
- Can also impose geography.

Demonstrating the Model

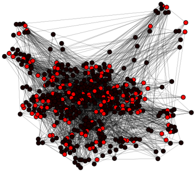


Individual Sensitivity Vs Ensembles

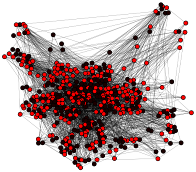
Chance of success depends on model parameters:



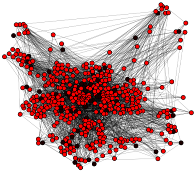
t_1



t_2



t_3



t_4

Individual Sensitivity Vs Ensembles

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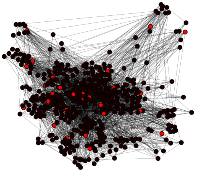
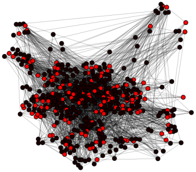
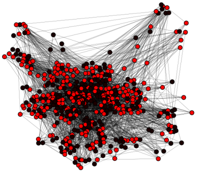


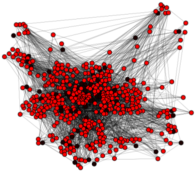
t_1



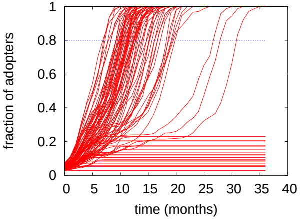
t_2



t_3



t_4



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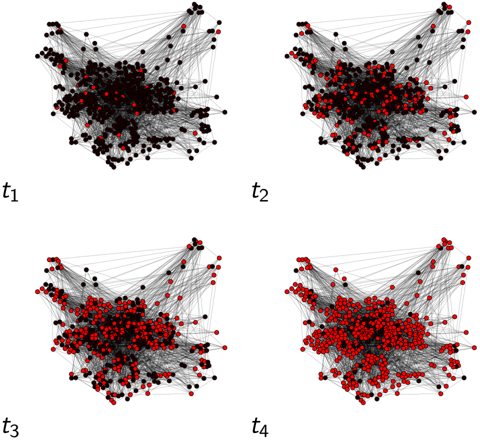
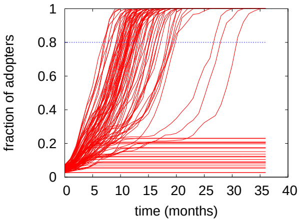
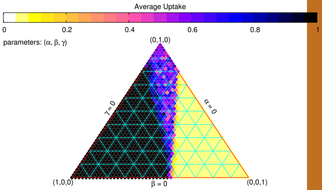


t_1 t_2

t_3 t_4





Methods of Analysis

Analysis [3]

- Simple cases:
  - $\alpha p > \theta$: Immediate uptake below $\beta = 1 - \gamma - \frac{\theta}{p}$,
  - $\alpha p + \gamma m_0 > \theta$: values below $\beta = 1 - \frac{\theta}{p} - \gamma\left(1 - \frac{m_0}{p}\right)$ successful.
- Simple *mean field*: assume average $\bar{s}_i = m$:

$$\begin{aligned} u = \alpha p + (\beta+\gamma) m_0 &\geq \theta, \quad \text{i.e.,} \\ p + (m_0 - p)(\beta+\gamma) &\geq 0; \quad \text{hence:} \\ \beta + \gamma &\leq \frac{\theta - p}{m_0 - p}, \end{aligned} \tag{3}$$

Local neighbourhood sensitivity

- Given individuals have a certain $\theta, p, \alpha, \beta, \gamma$ and m, require critical fraction of *active* neighbours:

$$s^* = \frac{\theta - \alpha p - \gamma m}{\beta}, \tag{4}$$

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$$X_i \equiv \sum_j A_{ij} x_j \geq \lceil k_i s^* \rceil \equiv X_i^*, \tag{5}$$

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- combining (4) and (5) gives X^* regions of β, γ plots...

Comparison with Watts-Strogatz

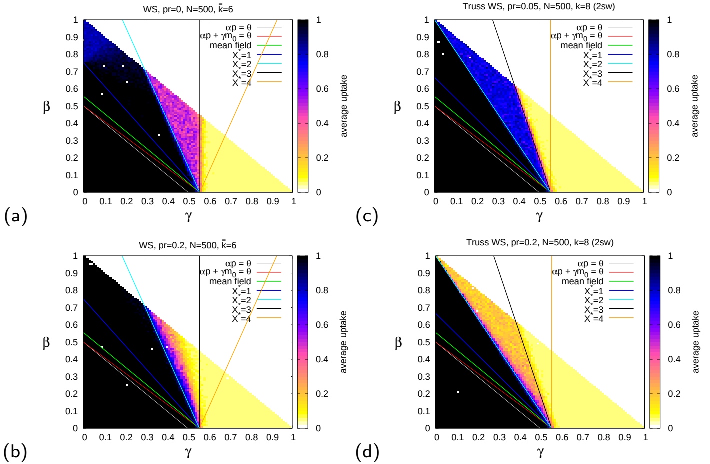

Figure: **(a)** 1D $\bar{k} = 6$, $p_r = 0$, **(b)** 1D $\bar{k} = 6$, $p_r = 0.2$; **(c)** truss $k = 8$, $p_r = 0.05$, **(d)** truss $k = 8$, $p_r = 0.2$.

Chance and rate of uptake

- Number of active neighbours can be sufficient by chance with probability[4]:

$$P(X \geq X^*) = \sum_{n=X^*}^{k} \binom{k}{n} m^n (1-m)^{(k-n)}, \qquad (6)$$

  - $X^* = \lceil k(\theta - \alpha \mathbf{p} - \gamma \mathbf{m})/\beta \rceil$.

[4] assume $k_i = k$ and random network.

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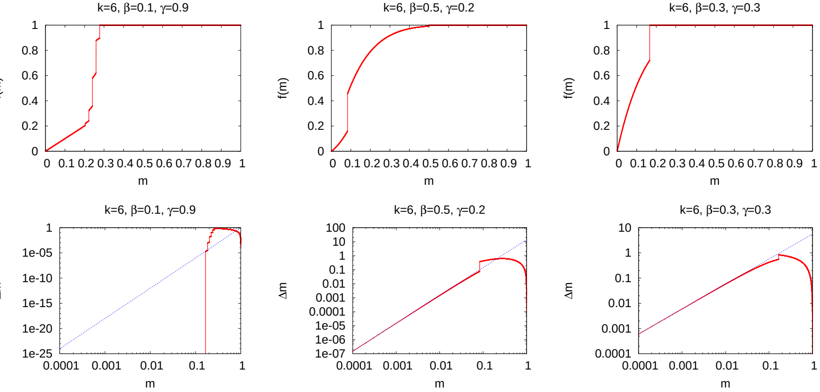
  - $X^* = \lceil k(\theta - \alpha p - \gamma m)/\beta \rceil$.
- This is fraction of remaining $(1-m)$ of individuals to adopt, increasing overall average:

$$\Delta m = (1-m)P(X \geq X^*). \tag{7}$$

[4] assume $k_i = k$ and random network.

Growth of initiated cluster

$$m' = m + (1 - m)P(X \geq X^*) \equiv f(m).$$



Effect of initial seed size

$$\Delta m = (1-m) \sum_{n=X_i^*}^{k_i} \binom{k_i}{n} m^n (1-m)^{(k_i - n)},$$

- for small m:

$$\Delta m \sim \binom{k_i}{X_i^*} m^{X^*}. \tag{8}$$

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- For $X^* > 1$ disproportionate effect of low initial seed sizes (*"funding"*).
  - E.g. $k = 15$, $X^* = 4$, $\Delta m \sim 1365 m^4$.
    Half initial m_0 takes 8 times as long to reach target.

Other Networks

UNIVERSITY OF BATH

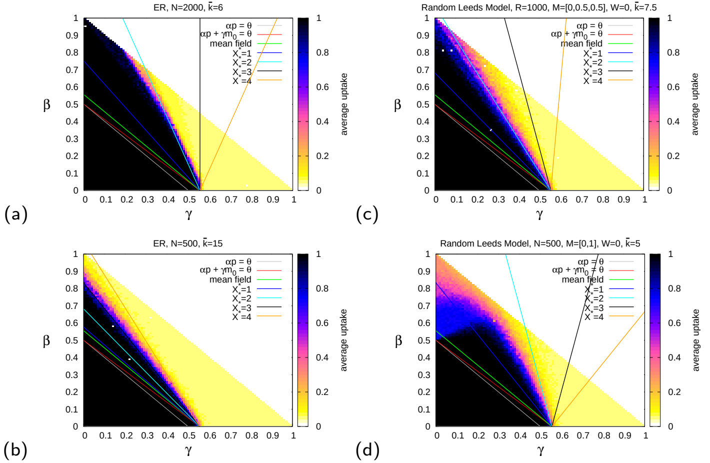
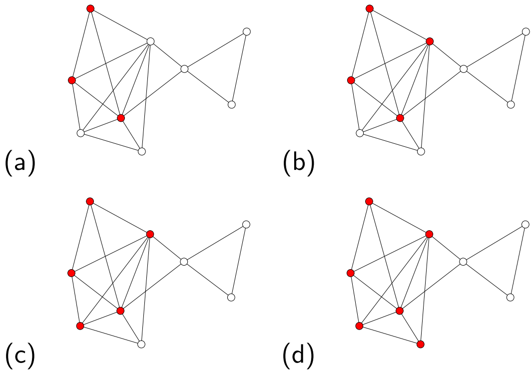


Figure: **(a)** Random $N = 2000$, $\bar{k} = 6$, **(b)** random $N = 500$, $\bar{k} = 15$, **(c)** geographic, connected communities, $\bar{k} = 7.5$, **(d)** disconnected communities, $\bar{k} = 5$.

The Problem of Clustering

Clustering creates non-independent neighbourhoods:



The Problem of Clustering

Enhances expected uptake:

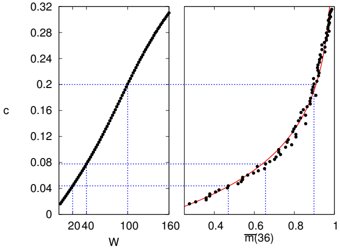


Figure: Expected uptake for clustered random network, with number of *groups* W determining level of clustering c.

- Only one "success" required in network for spreading to occur.

Modelling Inhomogeneity

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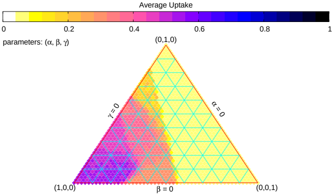
(a)



(b)

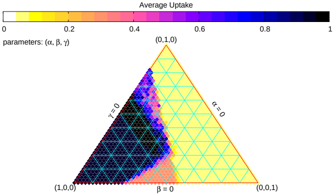


Figure: Thresholds distributed over three values. (a) 28% of $\theta = 0.25$, 17% of $\theta_2 = 0.45$, 5% of $\theta_3 = 0.75$, 50% of $\theta_4 = 1$; (b) 28% of $\theta_1 = 0.25$, 67% of $\theta_2 = 0.45$, 5% of $\theta_3 = 0.75$.

Modelling Inhomogeneity

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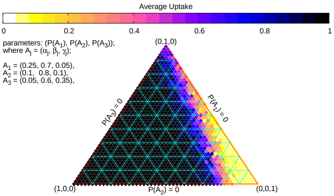
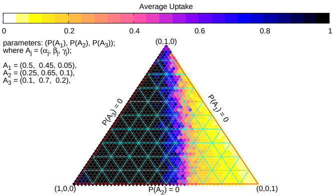


(a)



(b)

Figure: The population is divided into three archetypes and individual nodes are each assigned to an archetype $A_j = (\alpha_j, \beta_j, \gamma_j)$. (a) $A_1 = (0.25, 0.7, 0.05)$, $A_2 = (0.1, 0.8, 0.1)$, $A_3 = (0.05, 0.6, 35)$. (b) Thresholds are also distributed, with: $A_2 = (0.25, 0.65, 0.1)$, $A_3 = (0.1, 0.7, 0.2)$

Real World Scenarios

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Using survey data

- Survey data including info on behaviours.
  - Over 1050 valid responses received from residents of Leeds.
- Data used as a guide rather than definitive source,
  - used to narrow choice of structure and parameter values,
  - also to illustrate potential applications.

Model element	Parameter	Question / Data
Network	number of active individual / group connections.	Q. on who talks to whom about energy.
Threshold	θ	Q. on house type, tenancy and income.
Node archetypes	α, β, γ	Defra types of pro-enviro. behaviour

Parameterising the Models

Model Feature	Parameters	Data (if used)
Network structure	N, G, M | W, L	Survey | Assumption
Individual connections	I | L	Survey | Assumption
Group connections	G | L	Survey | Assumption
Archetypes	$A_i = (\alpha_i, \beta_i, \gamma_i)$, $P(A_i)$	Simulation
Threshold	θ | $P\theta$	Survey | Assumption

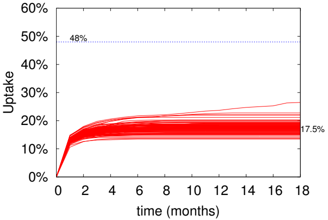
Modelling Scenarios

- Different **scenarios** studied by varying *dynamical model* and *network parameters*.

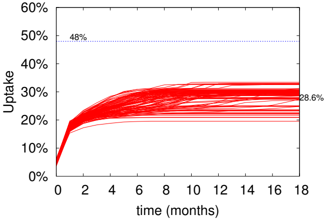
	Baseline	**Seeded**	**Community**	**Incentives**	**Snowball**
Model Param.	Do Nothing	Give efficiency measure to some (random) individuals	Give efficiency measure to whole communities.	Advertise a money off scheme.	Recommend-a-friend discount voucher scheme.
Links	Data based	–	–	–	**Increase**
Threshold	Data based	–	–	**Lower**	**Lower**
Initial Seed	Unforced	**Random**	**Target**	–	–

Real World Scenarios

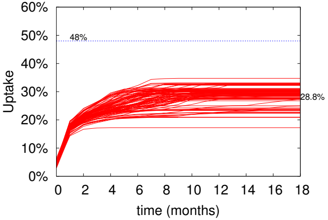
Baseline



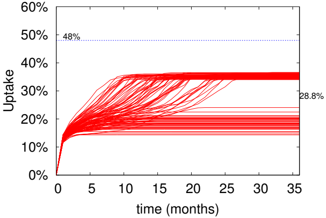
Seeded



Community

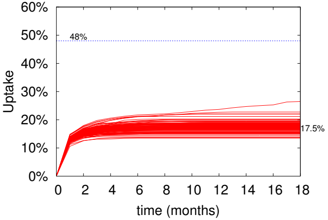


Incentives

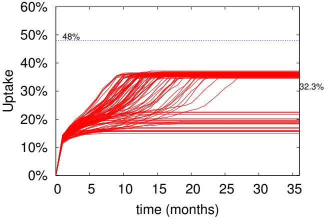


Real World Scenarios

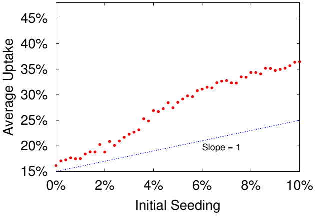
Baseline



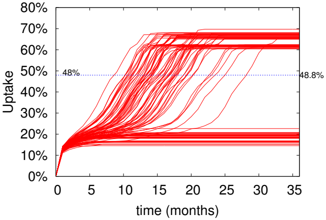
Snowball



Seeding Level

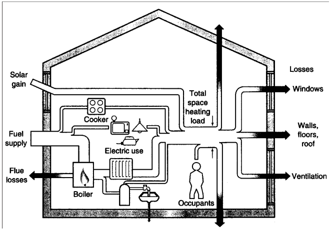


Snowball + Extra



Future Energy Networks

Domestic Energy Networks

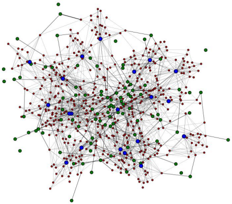


BREDEM-12, B.R. Anderson, et al., BRE (2001)

- Networks models of heat flows in buildings.
- Interaction network between occupants, building, technology.
- Smart systems & automated management of building energy.

Distributed Generation

- Renewables distributed to households across network are intermittent.
- Nodes can flip between energy *source* and *sink*.
- Problems of synchronisation and erratic inputs/outputs.
- Resonances could cause problems. . .



http://en.wikipedia.org/wiki/Distributed_generation

Smart Metering

- How do users interact to feedback from local network?
- What is ideal level of feedback?
- What is best strategy for role-out of meters?

Energy Retailers Association/PA

http://sierramadretattler.blogspot.com

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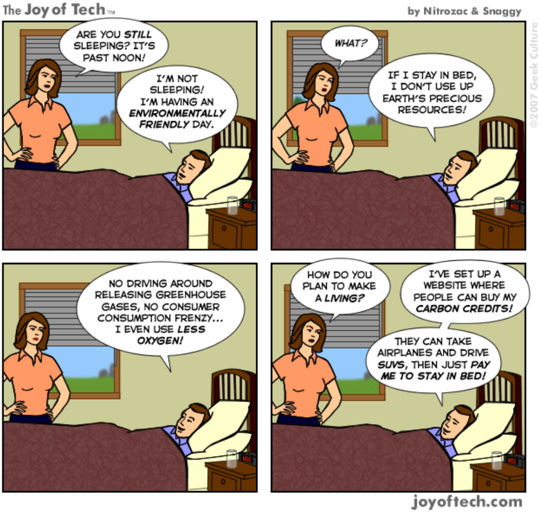
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