# Modelling the uptake of domestic energy technologies via local networks and integrating real-world data

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## Introduction

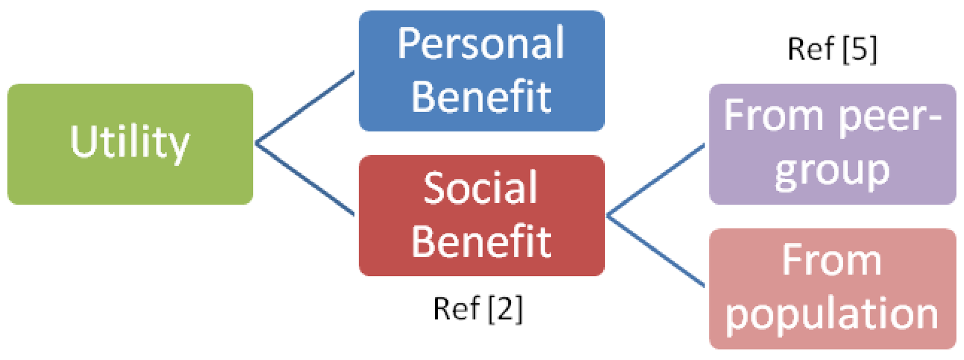
- Companies and policy-makers are in a position to influence residents and businesses to adopt domestic energy measures and reduce energy demand;
- Tools are needed to support decision-makers in achieving their energy and climate change targets [1];
- Quantification and integration of real-world data into mathematical and simulation models is needed for them to be reliable and usable as tools by strategic planners.

## Objectives

1. To develop tools for modelling diffusion of energy technologies via networks of households, in order to aid decision-making in local authorities;
2. To use real-world empirical data to guide the models towards more accurately representing heterogeneous populations and studying the effect this has on the model results.

## Modelling Uptake of Innovation

Householder decisions to adopt a particular innovation are based on a combination of factors:




**Total Utility** to household[3]:

$$u_i = \alpha_i p_i + \beta_i s_i + \gamma_i m,$$

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

1. Households are represented as *nodes* on a network.
2. People communicate via peer-to-peer interactions.
3. Interactions represented by *links* between nodes.

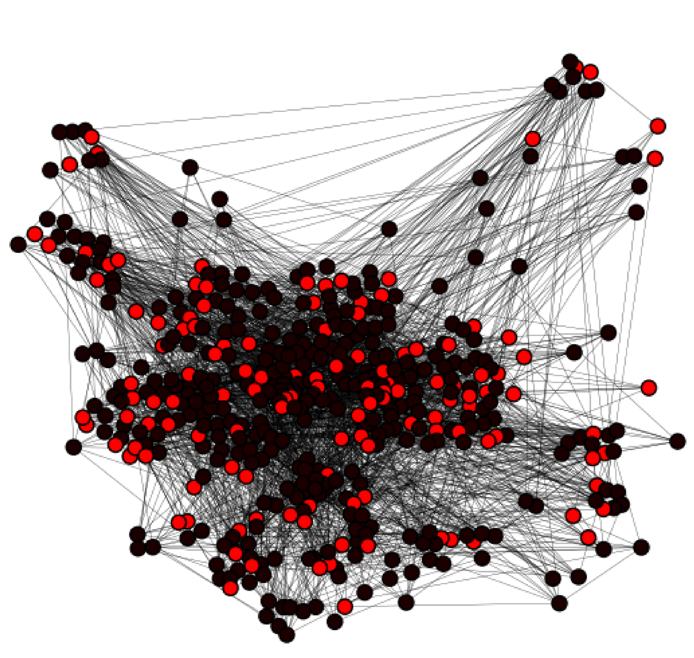


**Figure 1: Network Model**

4. Each node $i$ has adoption state variable $x_i = 0, 1$.
5. Dynamical equations determine individual uptake.

**Adoption Rule:**

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

- $\theta_i$: threshold (barriers, costs etc.),

## Modelling Social Networks

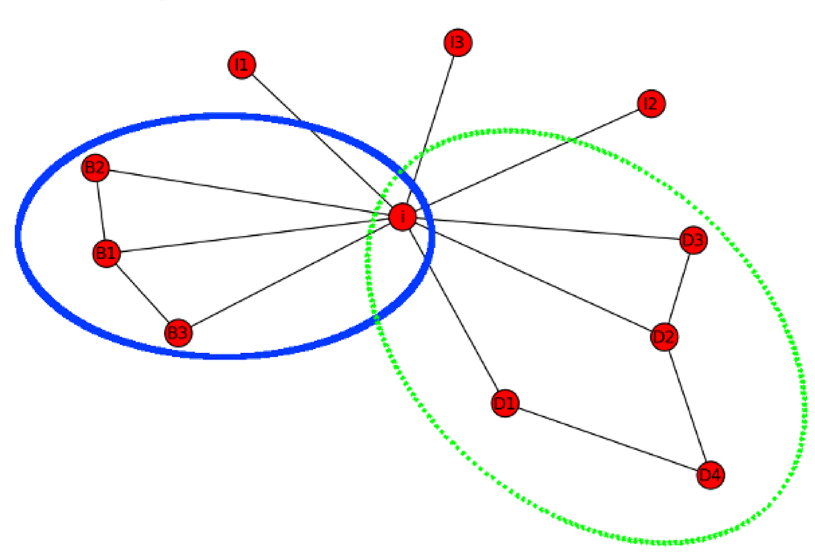


**Figure 2: Links established between nodes either individually or via groups[4] — social, workplaces, etc. Here there are $N = 11$ nodes, with node $i$ connected to $G = 2$ from a total of $W$ groups overall. There are $L = 3$ links established per group and individually.**

## Integrating Real-World Data

- A survey of Leeds residents was undertaken in May–June 2011 in order to populate the model with empirical data.
- The survey gathered information about household type and tenure, socio-economic data, geographic location, and questions on who people spoke to (and therefore were connected with) specifically about energy-related issues.
- 1068 valid responses were received.
- The table below shows how empirical data from the survey has been used in the model.

| Model Feature | Parameter | Data Source |
|---|---|---|
| *Network structure* | $N, G, M \mid W, L$ | Survey \| Assumption |
| *Individual connections* | $I \mid L$ | Survey \| Assumption |
| *Group connections* | $G \mid L$ | Survey \| Assumption |
| *Archetypes* | $A_i = (\alpha_i, \beta_i, \gamma_i)$, $P(A_i)$ | Simulation |
| *Threshold* | $\theta \mid P\theta$ | Survey \| Assumption |

- Individual preferences and social network influences are important factors in the adoption of energy innovations; local authorities have the means to potentially harness these influences to their advantage in encouraging increased adoption.
- Since expected uptake of an innovation emerges as a result of adoption behaviour of individuals connected on a social network, in order for us to investigate potentially successful interventions, a complex-systems perspective is needed.

## Systematic Investigation of Parameters

Individual simulations *with the same parameters* can depend sensitively on model details and initial conditions:

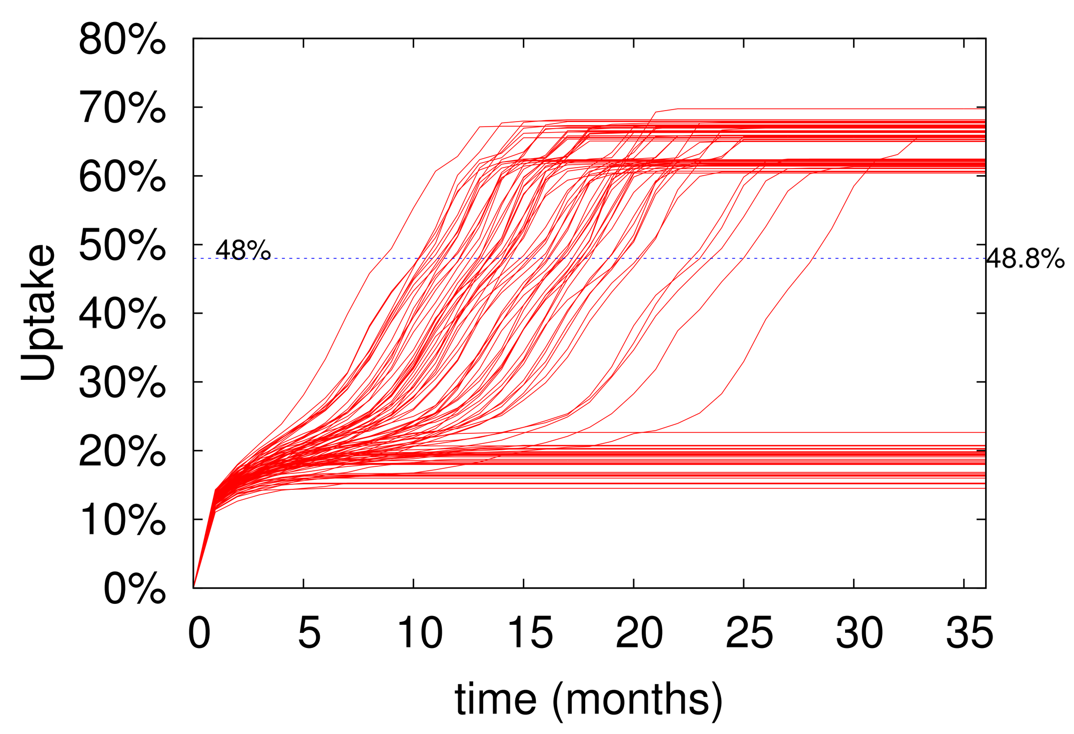



**Figure 3: Examples of 100 individual runs with same parameters but different details and seed.**

Need to look at *ensemble averages* over many realisations.

**Method:**

**(1) pick a set of parameters,**
**(2) perform 20 runs for 36 time-steps,**
**(3) plot average uptake for that set of parameters,**
**(4) can study sensitivity to various parameters.**

## Results

A selection of results is shown here.

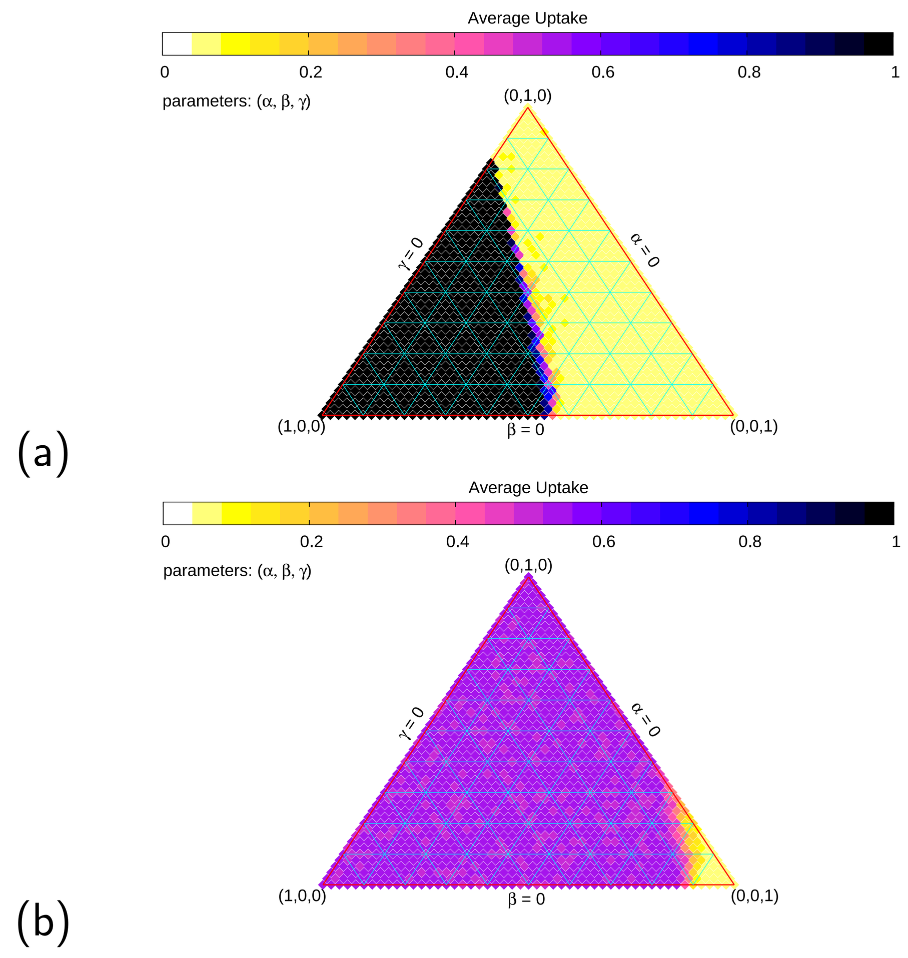



**Figure 4: Different values of two thresholds, each assigned to half the nodes. (a) $\theta_1 = 0.45, \theta_2 = 0.25$ (b) $\theta_1 = 0.9, \theta_2 = 0.1$. The shift in the behaviour demonstrates that the choice of thresholds is crucial to the outcome of the simulations.**

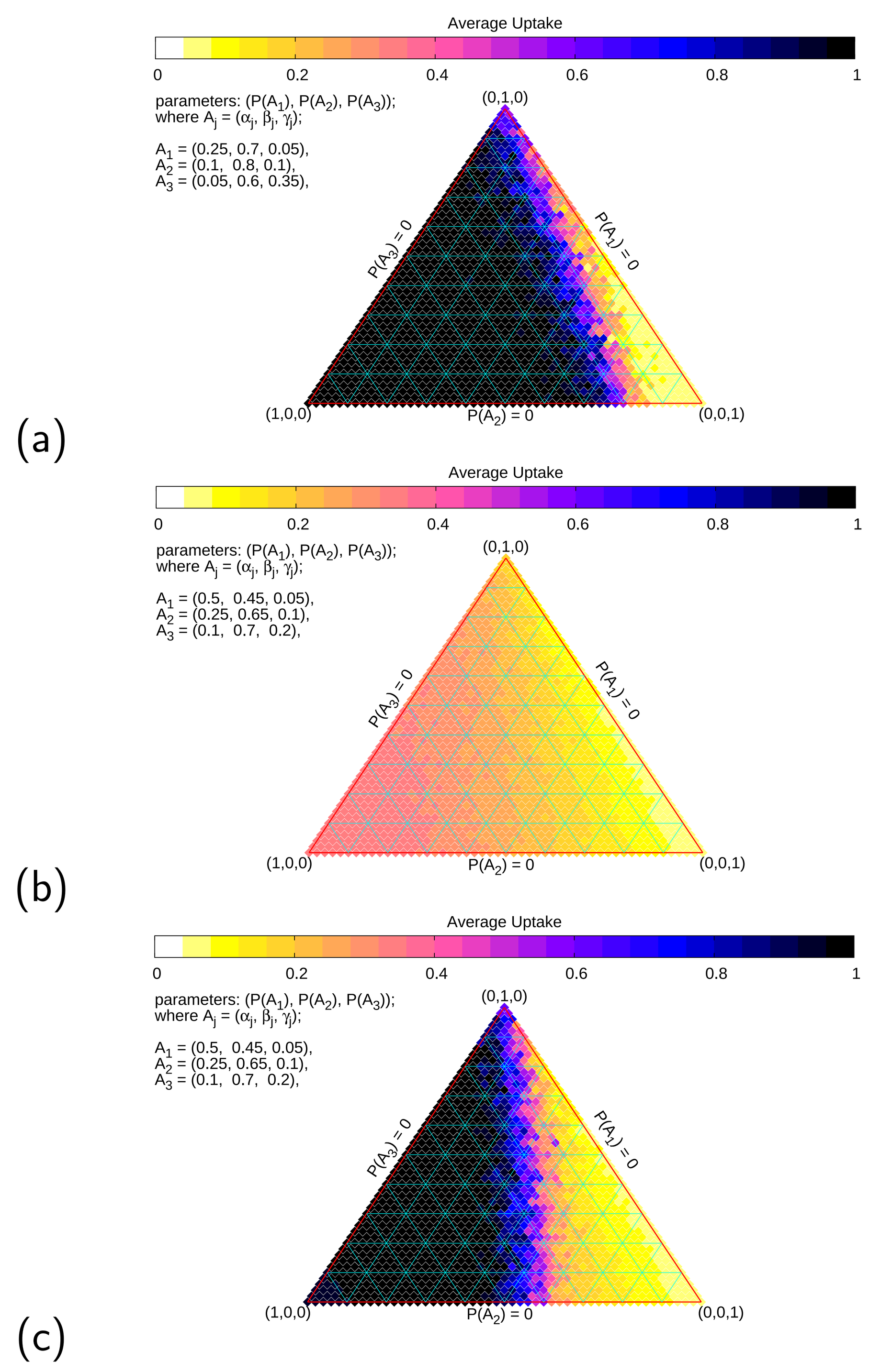



**Figure 5: The population is divided into three archetypes $A_j = (\alpha_j, \beta_j, \gamma_j)$. Each point on the plot is for a different set of relative proportions of the population $(P(A1), P(A2), P(A3))$. (a) Single threshold $\theta = 0.25$. (b) Thresholds are distributed with $\theta = (1, 0.75, 0.45, 0.25)$ with proportions (0.5, 0.05, 0.17, 28). (c) The $\theta = 1$ threshold is lowered to $\theta = 0.45$. The difference between the results is due to the different distribution of archetypes and thresholds.**

## Conclusions

- We have developed a model for exploring the parameter space to investigate what factors are important in the diffusion of innovations on a real-world social network.
- We extended our basic dynamical network model to integrate empirical data (gathered via a city-wide survey) into the models in order to more closely represents a real social system.
- We have highlighted the need for new data to understand (in a quantitative way) householder barriers and drivers to adoption of energy-efficient innovations.
- The benefits to adopting network interventions are becoming clearer and this is certainly an area where further research is warranted.

## References

[1] Bale, C. S. E., Foxon, T. J., Hannon, M. J., and Gale, W. F. Strategic energy planning within local authorities in the UK: A study of the city of Leeds. *Energy Policy*, 48:242–251.

[2] Delre, S., Jager, W., Bijmolt, T., and Janssen, M. (2010). Will it spread or not? the effects of social influences and network topology on innovation diffusion. *Journal of Product Innovation Management*, 27(2):267–282.

[3] McCullen, N. J., Rucklidge, A. M., Bale, C. S. E., Foxon, T. J., and Gale, W. F. (2012). Multi-parameter models of innovation diffusion on complex networks. *SIAM Journal on Applied Dynamical Systems*, 12(1):515–532.

[4] Newman, M. E. J. (2003). Properties of highly clustered networks. *Physical Review E*, 68(2), 026121.

[5] Valente, T. (1996). Social network thresholds in the diffusion of innovations. *Social networks*, 18(1):69–89.

[6] Valente, T. (2012). Network interventions. *Science*, 337(6090):49–53.

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