

Socio-technical Trade-offs in Self-regulating Smart Grids

Evangelos Pournaras ^{#1}, Matteo Vasirani ^{*2}, Robert E. Kooij ^{!§3}, Karl Aberer ^{*4}

[#] *Chair of Computational Social Science
ETH Zurich, Zurich, Switzerland*

¹ epournaras@ethz.ch

^{*} *Distributed Information Systems Laboratory
École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland*

² matteo.vasirani@epfl.ch

⁴ karl-aberer@epfl.ch

[§] *Department of Computer Science and Engineering
Delft University of Technology, Delft, The Netherlands*

³ r.e.kooij@tudelft.nl

[!] *TNO*

Delft, The Netherlands

³ robert.kooij@tno.nl

Abstract—This paper illustrates socio-technical trade-offs in self-regulating Smart Grids. Social and technical factors such as robustness, discomfort and fairness are measured and evaluated using data from real-world operational Smart Grids projects. Results show a broad spectrum of socio-technical trade-offs required for effectively self-regulating Smart Grids. Such trade-offs can make future societies more participatory and self-sustainable.

This paper is a compressed contribution of earlier work [1], [2].

Index Terms—self-regulation, Smart Grid, demand planning, agent, robustness, discomfort, fairness

I. INTRODUCTION

Regulating critical infrastructures, such as Smart Grids, is a challenge. A complex interplay between social and technical factors govern the capability of Smart Grids to match supply and demand in real-time. On the one hand, information and communication technologies (ICT) enable consumers to participate in demand-response programs and energy markets. These technologies are based on sensors, controllers and actuators that regulate the demand of each household in real-time and a personalized way. Consumers can continuously adapt their comfort level, e.g., the temperature setpoints of their air-conditioners, based on their preferences and social profile. On the other hand, Smart Grids are built by physical assets that can fail at any time, e.g., power lines, generators, etc. Supply may not be available to meet demand and, therefore, the social preferences may collectively come in conflict with technical system constraints. The gap between social and technical factors in Smart Grids becomes even larger when social preferences are not fairly regulated under certain technical constraints.

This paper illustrates computational trade-offs that bridge the regulatory gap between social and technical factors governing Smart Grids. More specifically, three regulating socio-technical factors are studied: (i) *robustness*, (ii) *discomfort* and (iii) *fairness*. This paper claims that improving robustness via demand-side energy management causes a level of discomfort for consumers that also influences fairness in the population of consumers in regards to the level of discomfort they experience. This paper quantitatively evaluate trade-offs between robustness, discomfort and fairness under demand planning. These trade-offs can be regulated via intelligent

selections performed by software agents that plan the demand of consumers. The performance of demand planning is experimentally evaluated with real data from operational Smart Grids. Results show that social and technical factors in Smart Grids can be self-regulated via decentralized demand planning.

II. SOCIO-TECHNICAL SELF-REGULATION

This section outlines three regulatory socio-technical factors that govern Smart Grids. These factors can be quantified and measured as shown in earlier work [1], [2].

A. Robustness

The extent to which supply can meet demand or demand can be adjusted to available supply is an indication of system robustness. Robustness can be improved by demand planning that aims to alter the aggregate demand curve by, for example, making it more homogeneous over time [3]. This paper distinguishes two technical methods for improving robustness: (i) *load-shifting* and/or (ii) *load-adjustment*. The former shifts load from high peak to low peak times without a significant influence in the average load over time [4]. The latter method decreases (or increases) average load via, for example, incentives mechanisms [5]. Both methods can be applied to improve robustness by preventing disruptions, such as black-out events, or minimize their impact when they occur [6]. They can be also used for a more efficient utilization of energy resources, e.g., renewables.

B. Discomfort

On the other hand, discomfort refers to the social impact of load-shifting and load-adjustment to obtain a higher robustness. This paper distinguishes two types of discomfort that consumers may experience: (i) *shifting discomfort* and (ii) *adjustment discomfort*. Shifting discomfort is related to the inconvenience experienced by load-shifting. For example, discomfort can be experienced when people shower at later or earlier time than the intended one. Adjustment discomfort is related to the inconvenience experienced by load-adjustment. For example, low temperature setpoints of air-conditioners during winter may cause discomfort. Moreover, a discomfort experience depends on human perception, e.g., when it is cold or how cold it is, and therefore, the discomfort impact of load-adjustment and load-shifting is not the same among different social groups of consumers.

C. Fairness

Most demand-side energy management methods do not consider how discomfort is distributed among consumers. The distribution of discomfort indicates a degree of fairness in the sense of how socially equal the contribution of consumers to the robustness of Smart Grids is. Unfairness is defined by the dispersion of discomfort that consumers experience (or perceive) when future demand is planned in response to a load-adjustment or load-shifting event.

III. EXPERIMENTAL EVALUATION

Socio-technical self-regulation is evaluated via a novel combination of the following methods: (i) Mining historic demand data¹ to plan future demand. (ii) Modeling of user preferences using survey data¹. (iii) Fully decentralized demand-side energy management with EPOS, the *Energy Plan Overlay Self-stabilization system* [3], [7]. Robustness, discomfort and fairness are mathematically defined and measured using the first two methods as shown in detail in earlier work [1], [2].

Figure 1 illustrates the performance of 8 selection functions with which demand plans are selected by the agents of EPOS. While MAX-ENTROPY provides the highest robustness, adjustment discomfort is minimized by MAX-DEMAND, RANDOM and MAX-LOAD-FACTOR. Selections functions can be used to make socio-technical trade-offs for self-regulating demand in Smart Grids

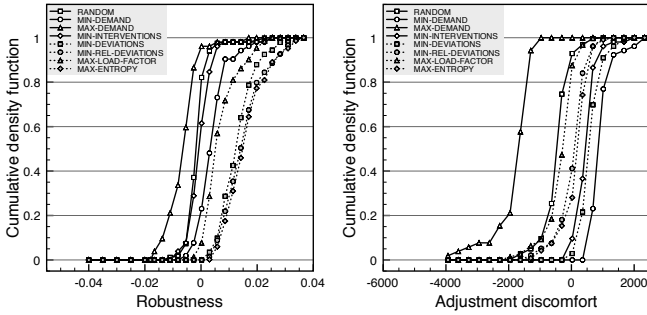


Fig. 1. Cumulative distribution functions of robustness and adjustment discomfort.

Figure 2 illustrates how planning configurations influences fairness. More specifically, software agents in EPOS regulate household demand by selecting a plan to execute from a number of alternatives l . The higher the number of plans that agent generates, the higher the robustness is [3], [7], [2]. This is also shown in Figure 3 in which the power peaks during evening hours are significantly shaved when the number of plans increases.

However, a larger number of plans increases unfairness in the population as shown in Figure 2b. Moreover, the temporal factor is also influencing unfairness. More specifically, during winter times when demand is higher, unfairness is also higher.

These results provide empirical evidence of how Smart Grids can be self-regulated by making socio-technical trade-offs. Policies, decision-making processes and even reward mechanisms can be designed based on this evidence as shown in earlier work [2].

¹Results shown here are computed from the data of the Electricity Customer Behavior Trial project in Ireland. Available at <http://www.ucd.ie/issda/data/commissionforenergyregulationcer/> (last accessed September 2013)

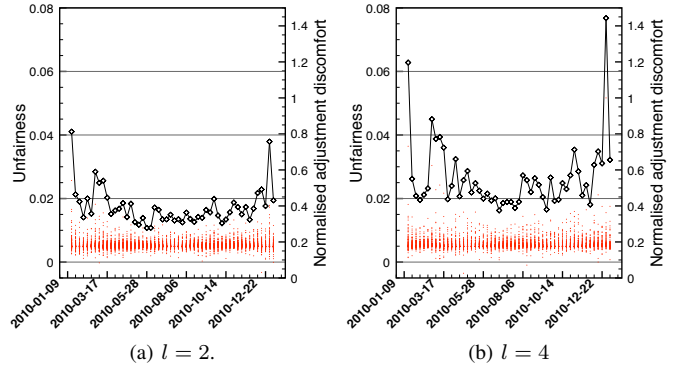


Fig. 2. The values of adjustment discomfort under load-adjustment for agents with different number of possible plans l (dots with values on the right Y axis). Their dispersion shows the unfairness (line with values on the left Y axis).

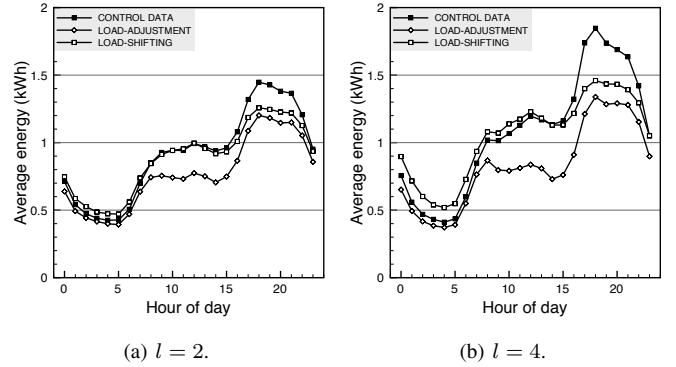


Fig. 3. Average daily energy demand of agents with different number of possible plans l .

IV. CONCLUSION

This paper concludes that both social and technical factors are critical for effectively self-regulating Smart Grids. By measuring and understanding a broad spectrum of socio-technical trade-offs in Smart Grids, future societies can become more participatory and self-sustainable.

REFERENCES

- [1] E. Pournaras, M. Vasirani, R. Kooij, and K. Aberer, "Measuring and controlling unfairness in decentralized planning of energy demand," in *Energy Conference (ENERGYCON), 2014 IEEE International*, May 2014, pp. 1255–1262.
- [2] E. Pournaras, M. Vasirani, R. E. Kooij, and K. Aberer, "Decentralized planning of energy demand for the management of robustness and discomfort," *Industrial Informatics, IEEE Transactions on*, vol. 10, no. 4, pp. 2280–2289, Nov 2014.
- [3] E. Pournaras, M. Warnier, and F. M. T. Brazier, "Local Agent-based Self-stabilisation in Global Resource Utilisation," *International Journal of Autonomous Computing*, vol. 1, no. 4, pp. 350 – 373, Dec. 2010.
- [4] M. Stadler, W. Krause, M. Sonnenschein, and U. Vogel, "Modelling and evaluation of control schemes for enhancing load shift of electricity demand for cooling devices," *Environmental Modelling & Software*, vol. 24, no. 2, pp. 285–295, Feb. 2009.
- [5] P. Joskow and J. Tirole, "Reliability and Competitive Electricity Markets," *The RAND Journal of Economics*, vol. 38, no. 1, pp. 60–84, May 2007.
- [6] E. Pournaras, M. Yao, R. Ambrosio, and M. Warnier, "Organizational Control Reconfigurations for a Robust Smart Power Grid," in *Internet of Things and Inter-cooperative Computational Technologies for Collective Intelligence*, ser. Studies in Computational Intelligence. Springer-Verlag, Jan. 2012, vol. 460, ch. 8, pp. 189–206.
- [7] E. Pournaras, "Multi-level reconfigurable self-organization in overlay services," Ph.D. dissertation, Delft University of Technology, March 2013.