Chapter 51
Providing a Scientific Arm to Renewable Energy Cooperatives

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51.1 Introduction

Recent research on sustainable energy and development planning indicates a shift towards renewable energy resources, and the adoption of energy conservation techniques is gaining ground towards tackling energy poverty and meeting large-scale energy efficiency (EE) [1]. However, for EE to be attained, stakeholders (i.e. utility companies, grid regulators, end users) need to get actively involved.

One of the most significant parts of the current energy market is the European renewable energy sources cooperatives (REScoops). More than 2397 REScoops across Europe, collectively having more than 650,000 members,[1] provide participating citizens the opportunity to buy renewably generated electricity at fair prices, to democratically react with other members and co-decide the cooperative's future, and to be autonomous and independent with respect to energy. Given these features and benefits, REScoops organize events, such as meetings, conventions, etc., in order to raise their members' energy awareness. Thus, it is expected that when end users join forces in an energy cooperative, they become more active regarding energy conservation and efficiency.

[1]Data according to the European Federation of REScoops (REScoop.eu).

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This anticipated REScoops' "high energy efficiency potential" has, of course, to be realized and showcased in practice. To this end, the use of scientific tools and methods to (a) evaluate REScoops' EE performance and (b) boost their capabilities to actually achieve exceptional EE behaviour, is imperative so as they can meet their wider environmental, societal, and economic set targets. In particular, three key axes of scientific research are in interplay when one attempts to study and positively influence REScoops' EE behaviour. First, there is a need to employ statistical analysis tools to quantitatively assess the level of REScoops' EE effectiveness. Second, behavioural analysis techniques need to be used in order to support the statistical analysis findings and obtain additional quantitative as well as qualitative intuitions regarding REScoops' best practices (current and future ones). Third, *modern artificial intelligence* methods (including techniques from machine learning, game theory, decision theory, and multi-agent systems) can be key *(i)* to automate REScoop business and also *(ii)* to enable their participation in complex *demand-side management* schemes that require advance or real-time rational decisions regarding providing or consuming energy, in order to promote renewable energy use and avoid imbalances in the electricity grid load [2–4].

Indirect mirroring of this view, the REScoop Plus H2020 project (https://rescoop.eu/european-project/rescoop-plus) aims to gather available information and data from various European REScoops and demonstrate that participation in such a cooperative raises energy awareness and contributes to the accomplishment of the challenging goal of EE. Moreover, a central REScoop Plus goal is to promote a better understanding and cultivate the behavioural change of the cooperatives' engagement. In order for those goals to be met, it was essential to conduct a careful logging of and *statistical analysis* over the energy data stored by the REScoops, as well as the current state of their engagement in energy efficiency. Such tasks are imperative in order to support the claim that REScoop engagement promotes energy sobriety; and associate consumption reduction with specific behaviours, ICT tools, and EE practices. Second, it was essential to conduct an *in-depth behavioural analysis* regarding current EE practices and lay the ground for identifying "best practices" to be adopted. Third, there is a need to equip REScoops with modern *intelligent decision-aiding tools* that will assist them in their current business and expand it to include participation in automated demand-side management schemes. In the remainder of this chapter, we provide more intuitions on these key scientific axes and tools and showcase their use on the REScoop Plus project and other real-world settings.

51.2 Statistical Analysis of REScoops' Data and Behavioural Patterns

In this section, we present in brief the statistical analysis conducted in REScoop Plus. Specifically, we outline the methodology and statistical techniques used; and we present the key results of this analysis.

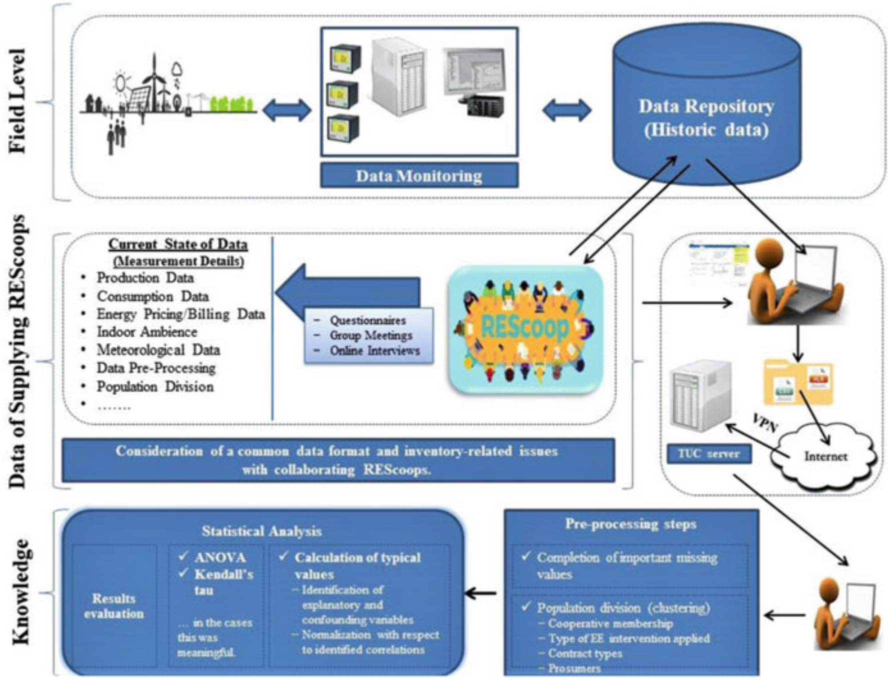

Fig. 51.1 Overview of a statistical analysis methodology for REScoops [5]

The design of a research methodology in order to conduct a statistical analysis of energy-related data is a complex process that requires significant technical expertise. There are many adjustments required in order to reach the optimum balance between reliability, accuracy, and significance. In this section, the methodological approach and critical issues to be considered are outlined. In brief, our approach in the REScoop Plus project consists of the following steps, also depicted in Fig. 51.1:

- Identification of the current state of the data from the participating REScoops
- Specification and adoption of a common data format and settling of inventory-related issues
- Receiving the datasets: Potential completion of values missing from third-party sources
- Analysing the development of the average yearly consumption for all cooperatives and separating all possible variables that might influence consumption (climate, habitual changes, etc.): Population clustering, identification of explanatory and confounding variables
- Validating the decrease in average consumption. Also, potentially checking whether there is a decrease in usage of conventionally produced energy (from non-renewable resources); performing hypothesis testing, following, e.g. n-way ANOVA [6] (includes identification of degree of correlation among variables); derivation of typical consumption curves for each cluster (includes normalization with respect to identified correlations)

51.2.1 Conducting the Actual Statistical Analysis

Given an identified methodology, one then needs to make choices regarding the actual statistical tools to be used for data analysis. In the REScoop Plus case, we utilize two well-known approaches, i.e. statistical hypothesis testing and analysis of variance (ANOVA). The latter is the main method we adopt in our work. According to this procedure, multiple subject groups are compared against each other with respect to average values and variances of certain measures [6]. For our purposes, the subject members are going to be divided into control and testing groups, i.e. some are going to apply EE interventions, while others are not. ANOVA is going to be used to assess the effectiveness of each EE intervention type when applied to different member groups. In some detail, we can use ANOVA to test how different EE interventions and incentives (factors) influence consumption for each energy end user (observations). By filling the ANOVA table with the observations corresponding to the various factors, we will find out the correlations between these variables and discover if the factors are additive. Also, if information on non-REScoop members is available, we can use ANOVA to compare the performance of groups of REScoop members with that of non-REScoop ones.

However, the exact analysis methodology strongly depends on the actual data that REScoops offer; thus, the final decision regarding the statistical analysis method is always anticipated to be subject to changes until the actual datasets are obtained. Also, ANOVA assumes that the data come from normal distributions, which is not always the case when it comes to electricity consumption data. Alternative methods for hypothesis testing are the Student's t-tests and the calculation of p-values [6].

To summarize, the statistical analysis technique used in REScoop Plus is in general as follows:

(a) Divide samples (i.e. members and clients of REScoops) into similarity groups with respect to (*wrt.*) factors such as contract type, type of EE intervention applied, etc.
(b) For each group: *(i)* calculate normalized average consumption for each individual consumer before and after the application of the EE intervention in question; *(ii)* calculate average reductions in normalized average consumption as a result of the EE intervention; and *(iii)* test statistical significance with appropriate techniques from the literature (according to the assumptions that the available data fulfil).
(c) Draw conclusions regarding the effectiveness of each EE intervention.

51.2.2 Preliminary REScoop Plus Project Statistical Analysis Results

In this section,[2] we present the results from the data gathering process, as well as some results regarding *(i)* a large Danish district heating cooperative, EBO, and *(ii)* a large Belgian electricity cooperative, Ecopower.

The submitted EBO dataset included monthly heating consumption values from 300 residential customers, which are cooperative members, for the period of May 2012 to September 2016. Additionally, EBO responded to past yearly consumption values of the members before joining EBO and also with a dataset from a non-cooperative company, containing monthly data samples that indicate the consumption of 1000 non-cooperative members. Most EBO member measurements were accompanied by information regarding the buildings' surface in square metres, the number of residents, additional building characteristics, and meteorological data, e.g. minimum, maximum, and average temperature values and heating degree days. The EE intervention that EBO has applied to their members is termed as "technical support". This intervention includes technical inspections by experts, suggestions for equipment or insulation upgrades, etc. As our results illustrate, this particular EE intervention was effective in reducing consumption when applied to the cooperative members. In particular, the treated customers achieved *20% reductions in their monthly kWh normalized by heating degree days' consumption on average*, after receiving the intervention. This indicates that "technical support" can be proven a valuable tool for other REScoops that also deal with district heating. Regarding statistical significance, we observed a $p\text{-}value < 0.05$, indicating that there is a significant difference between the sample distributions of the consumption measurements before and after applying this particular EE intervention. In addition, *Kendall's* τ *value* was <1, meaning that the two vectors containing the values before and after the EE intervention are only to an extent correlated; thus, given the observed significant reduction, actual changes in consumption behaviour have indeed occurred. Furthermore, our results show that the customers who became cooperative members *reduced their consumption (in kWh/m*^{2}*) by 19.92%*, as compared to the time before joining. Receiving technical support led to *a reduction of 21.42%* in *average heating energy consumption in kWh/(m*^{2} ** HDD)* and to *reduced* CO_2 *emissions by 274.13 kg* on average for the receiving members [5].

As far as Ecopower is concerned, consumption measurements were gathered on a yearly basis. The number of customers with measurements was significantly larger, totalling to 33,596 customers. The reported period regarded the years 2011–2015, and the number of residents for each building was included. Now, although Ecopower does not gather monthly data itself, some of their customers have

[2]We note that we actually have preliminary results for seven REScoops across Europe, but presenting these is obviously not the focus of this chapter. However, the reader can find those results in the public deliverables of the REScoop Plus project.

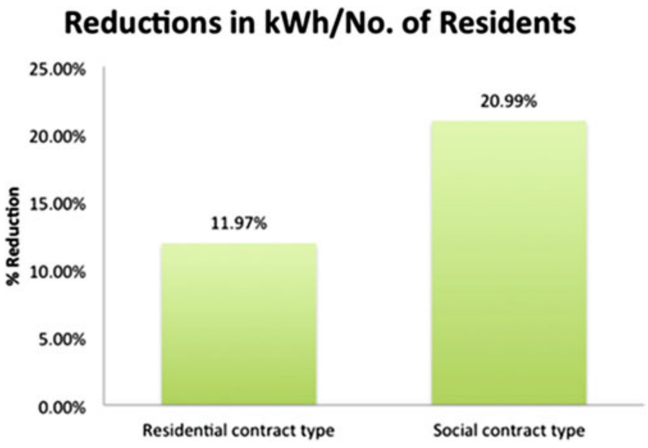

Fig. 51.2 Reductions in average yearly consumption of Ecopower customers adopting EnergieID [5]

Table 51.1 Significance tests regarding yearly average reductions achieved in *kWh/No. of residents* after applying the EnergieID EE intervention (two main categories of Ecopower customers) [5]

Contract type	Significance test	Result
Residential	*p*-value	2.105e−07
	Kendall's τ	0.572
Social	*p*-value	0.256
	Kendall's τ	0.578

subscribed to EnergieID,[3] a consumption monitoring and analysis software service, which includes the gathering of monthly consumption data, and also the buildings' surface in square metres, which is used as a normalizer for the consumption of these members. EnergieID service itself is the EE intervention analysed for its effectiveness in reducing electricity consumption [5].

Reduction results after applying the EnergieID EE intervention are summarized in Fig. 51.2 for two main categories of Ecopower customers and related significance tests are presented in Table 51.1.

Given these results, it is obvious that subscribing to EnergieID leads to significant reduction in the yearly average measurements for both main Ecopower contract types. Moreover, Ecopower clients who became cooperative members produced *235.12 fewer kg of* CO_2 *per year* [5].

[3]Energie ID is a digital platform for monitoring energy-related data, which offers the ability to consumers to manage efficiently their energy consumption.

Table 51.2 Presentation of integrated intervention framework

Strategy Types	Intervention	Type of policy instrument
Antecedent strategies	Commitment	Symbolic and hortatory tools
	Goal setting	Symbolic and hortatory tools
	Information Modelling	Capacity tools Capacity tools
	Tariffs Collective purchasing	Incentive tools Incentive tools
	Services	Incentive tools
Consequence strategies	Feedback Learning tools	Capacity tools
	Rewards	Incentive tools

51.3 Behavioural Analysis of REScoops Energy-Saving Policies

The transition to sustainable energy systems is not only a technological and economic challenge. It also requires a behavioural change, so that energy users use energy in more rational and efficient ways. Users' behavioural determinants can be targeted with policy measures to *(a)* encourage voluntary behaviour change and/or *(b)* to change the conditions under which they make decisions on energy use. Although the activities that REScoops undertake to some extent resemble those of other organizations, because of their particular organizational and business model as citizens' initiatives, REScoops, the cooperative model, are assumed to be well positioned for activities to influence and help their members and potential other energy consumers to save energy. This section discusses arguments why the REScoop model in energy supply can be an important contributor to reduce energy use by their members. Further, this section discusses measures that have been undertaken by REScoops studied in the REScoop Plus project.

REScoops use particular business and organizational models based on the cooperative model, a jointly owned and democratically controlled enterprise (see below). Therefore not all of the potential interventions are conceivable, like regulations. This raises the question, *whether REScoops are in a relatively good position to take certain measures and succeed in persuading customers to lower their energy consumption level*. In the REScoop Plus project, we compare in the first place REScoop members with other (commercial) energy users and non-REScoop members and not REScoops with other energy agents. We theorize that if REScoop members save more energy than conventional energy consumers, this might be due to one (or a combination) of the factors outlined below.

51.3.1 The Added Value of REScoops as Locally Based Energy Communities

The following arguments can be given why REScoops as a particular organizational or business model are in a relatively good position to stimulate energy among householders based on the lessons drawn from best practices (e.g. [7, 8]), REScoop policy documents [9], and the academic and professional literature (e.g. [10, 11]). We formulate seven arguments why the REScoop model in energy supply can be an important contributor to reduce energy use by their members [12].

A first argument would be that REScoops are in a good position to stimulate energy saving because of the scale level of their activities, which is mostly on the local level, i.e. close to citizens. Even if REScoops are national organizations, they often work with locally organized groups. In the literature on local sustainability, often the argument of proximity to citizens is used as an argument to take measures at a lower geographical level [13]. The REScoop model provides a good scale to run relevant local energy efficiency projects, such as investing in thermal insulation of dwellings, and that this would be a source of inspiration for others, including non-members [12]. Research shows that participating in decision-making related to sustainable consumption makes people more willing to cooperate in implementation actions and contribute to attaining energy efficiency goals [14].

A second argument would be that REScoops have a specific capacity and critical mass to stimulate energy saving among their members. Implementing and using measures and equipment to save energy takes a lot of time and requires both technological expertise and bureaucratic competence (e.g. to grant legal permits or subsidies). Sharing experiences, not reinventing the wheel, and the advantages of participating in activities together (in terms of costs or time) add to the capacity for action. For REScoops, it means that by facilitating consumers with measures like technological advice, administrative support, or upfront investments, a larger group of consumers can be motivated to actually participate in energy-saving activities. REScoops also have a certain critical mass to acquire the necessary expertise and motivate and assist citizens who are less motivated than those who are devoted to pursue sustainability goals [12]. A third argument we can label is social networking. REScoops are in an excellent position to share and link their activities, including their energy-saving actions, with other local actors like schools, sport clubs, local business firms, and housing associations. These organizations also have a stake in the energy and low carbon debates and are willing to take their own responsibility [15]. REScoops do not pursue profit maximization and often have similar idealistic and collective, community goals. Moreover, given their expertise, REScoops are often viewed by the other local organizations as good partners for energy and low carbon projects [12].

A fourth argument is the potential for awareness raising and education of the REScoop members. REScoops are in a good position to make their consumers more aware of energy use. They can also educate the larger community on the importance of energy efficiency by organizing and showing visible pilot projects in public buildings such as office buildings and schools, but also in individual consumer projects, and, for instance, the local community building [7]. Becoming a member of a REScoop presupposes already to be more aware of the importance of using energy than just being a passive consumer of a traditional energy supplier [12]. A fifth argument would be that REScoops are not only in a good position to make consumers aware of energy use, but they also tend to set energy saving as a social norm, viz. energy not only becomes a significant issue to the consumer and his/her household, but relative energy use and savings become less anonymous actions once users share their experiences with peers [16]. In this sense, REScoop energy-saving goals and average group energy-saving behaviour can become an element of goal steering, as a reference point for behaviour. A sixth argument is that REScoops are in a good position to generate trust towards citizens for them to take measures themselves and invest in energy efficiency or renewable energy technology appliances. This is especially important if these activities involve financial risks to be taken by the consumers in terms of making investments. Dealing with REScoops, who are often viewed as a very trustworthy partner to give advice and supply energy systems and appliances, might make people more willing and able to take investment risks [17].

Finally, in particular cases, e.g. “energy islands”, the common argument in sustainable energy production might occur. Commons are natural resources which are accessible to all members of a given community; they are not privately owned and therefore can potentially be consumed by all of them, presenting the risk of over-exploitation and depletion of the natural resource pool [18]. If the energy produced by the REScoop is seen as a common good, saving energy by individual consumers also makes it possible for more people to make use of the available renewable energy production [12].

51.3.2 Energy-Savings Measures Used by REScoops

In this section, we summarize what energy-saving tools and actions thus far have been developed by the REScoops participating in the REScoop Plus project and subdivided into antecedent and consequence strategies [12, 19].

Figure 51.3 shows the number of a large variety of *social and communicative antecedent strategies* we found among eight REScoops that were analysed. Most commonly used antecedent interventions concerned awareness raising, education, and behavioural change campaigns. Information (newsletters, social media, etc.) and (local) ambassadors were also used but more infrequently. Overall, 16 different interventions were identified.

There were certain incentive antecedent strategies that were used, most commonly transparent and single pricing (of renewable energy sold to householders), simple tariffs, and collective purchasing. Bonuses, giving out shares, and lending of money were also used only incidentally.

Fig. 51.3 Overview of social and communicative interventions (antecedent strategy)

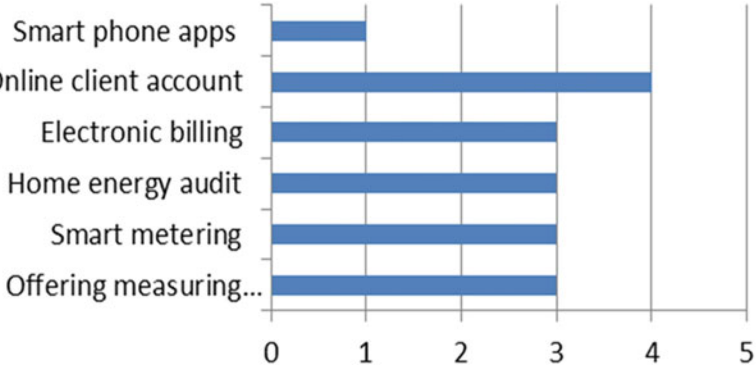

Fig. 51.4 Overview of (technical) feedback tools used by REScoop

The infrequent use of economic incentives might point to the fact that many of the REScoops observed were in the phase of starting off and experimenting with local projects and related business models. Finally, it is surprising that only one of the studied REScoops mentioned giving out shares as an incentive, since this forms a key principle of cooperatives.

The main *technical tools* deployed by the studied REScoops cover both direct and indirect feedback tools (see Fig. 51.4). At least half of the REScoop surveyed conveyed the use of consequence strategies, i.e. electronic billing, using online client accounts, smart metering, and organizing energy audits. As may be expected with consequence strategies, all tools and interventions used were technical or technology supported, often using smart (ICT) technology. Feedback from the REScoop staff to their members appears to mostly happen indirectly, i.e. via billing and online accounts on a web-based platform. There is no groupwise feedback or learning systems.

The overview shows that particular many antecedent strategies were used by REScoops. Compared with overviews of measures used by other energy agents, these measures are however not unique [20]. Particularly, many of the information tools used by REScoops are rather similar to what other energy supplier or governments and NGOs use. Consequence strategies were used less than antecedent strategies. Notwithstanding this fact, the consequence strategies' use varied a lot, and included both direct and indirect feedback tools. Consequence strategies were found to be well supported by online platforms and smart technology (i.e. smart metering). However, many REScoops are just on the verge of using feedback tools. REScoops were found to use a lot of technical equipment to provide feedback on energy consumption to their customers. REScoop members are more willing to use this equipment. This is not only technical equipment (but also uses other feedback mechanisms).

Measures are related to attaining goals, and one measure could serve different goals. Strictly speaking, we look for measures that address the goals investing in RES (producing more renewable energy) and saving energy. However, our inventory showed that for the studied REScoops, also other goals like delivering (energy) services, enlarging the size of total REScoop membership, stimulating the green energy transition, and climate change awareness raising are important. In the end, these other goals will contribute to the attainment of the first two main goals. A mix of existing policies aimed at stimulating reductions in energy can be called a policy package [21]. The overview is based on single measures or interventions on not measure packages. Additionally, one has to address situational factors like laws, regulations, neighbourhood factors, dwelling size, household size, income, employment status of occupants, ownership, stage of family life cycle, geographical locations, and personal comfort. Studies show that they all correlate significantly with household energy consumption (e.g. [22]).

51.4 Intelligent Agents and Game Theory of Demand-Side Management

Managing conventional electricity grids requires the continuous control of energy supply in real time, in order to keep the balance with demand undisturbed regardless of the demand levels. However, the integration of renewable energy sources (RES) entails that generation cannot be easily controlled because it heavily relies on weather conditions and is performed by large numbers of RES distributed across the network [2]. Moreover, electricity consumer preferences are complex due to distribution-related constraints and variable electricity prices and will become even more complex in the future due to electric vehicles' (EVs) usage [23]. All these call for the widespread use of effective demand-side management (DSM), that is, the use of schemes aiming to move electricity demand, to periods where consumption is lower or RES production more abundant [2, 4, 24].

This increased complexity requires replacing human intervention with intelligent agents and multi-agent systems [25]. By incorporating intelligent autonomous agents employing artificial intelligence and machine learning in the picture, important procedures—such as forecasting, real-time monitoring, and immediate reaction to emergent situations—become more effective, and reliability can be improved [3]. At the same time, although large industrial facilities might be, at least in principle, easy to incorporate in DSM schemes, this does not hold for every type of consumer. Especially for residential customers, daily habits can create negative incentives for DSM participation [26], since behavioural change also impacts customer comfort, not only finances. Here, intelligent agents can also be used to weigh individual costs and preferences, optimize individual consumption schedules, and deliver positive DSM impacts to scheme participants [3].

Now, optimizing individual consumption schedules is not enough: individual consumption is a very small world aggregate; thus, a single individual's actions induce imperceptible changes; and even when all individual actions do coordinate, herding effects may occur and new imbalances between supply and demand can arise at different points of the demand curve [3]. As a result, DSM operations have to be not only large scale but also coordinated. To this end, DSM contributors often join forces in cooperatives or virtual power plants so as to either consume or produce electricity in a coordinated fashion, mimicking the performance of a single large entity meeting the grid requirements [4]. The smooth operation of such entities and schemes is aided by the existence of rules and incentives that lead potentially selfish individuals to adopt a cooperative behaviour and coordinate their actions.

This is exactly the problem studied by mechanism design (MD) [27], a subfield of game theory that explores how to design a setting (viewed as a game) so that rational actors (or players) adopt a behaviour that helps meet the designer's objectives. In other words, MD schemes seek to offer incentives or counter-incentives for achieving desired social outcomes, to individuals that aim to maximize their own utility. Typically, such schemes strive to be incentive compatible, meaning that participants are incentivized to be truthful regarding their private preferences and that "gaming" the scheme leads to worse outcomes for "misbehaving" actors. As such, MD can be used to create DSM schemes that promote more efficient network operation, by granting economic and/or social gains to the participating individuals. Of course, scheme participation is determined by each actor individually; and the incentives must be sophisticated, so as to drive changes to human consumption habits while maintaining the profitability of energy sector businesses.

The emergence of effective, large-scale DSM is not a thing for the future. The requirement for large-scale, coordinated consumer action lies at the foundations of the fledging REScoops industry. REScoop activities include producing and trading renewable energy and also, already to some extent, providing DSM services. As such, they can naturally benefit from incorporating AI, MD, and other GT methods, in order to select the most appropriate participants for DSM actions, take individual preferences into account, and redistribute profits in a "fair" manner, rewarding truthful and accurate participants more than "unhelpful" and "misbehaving" ones.

An example of a day-ahead "electricity consumption shifting" scheme that employs mechanism design and machine learning solutions and which can be potentially adopted by REScoops that envisage expanding their business to demand-side management appears in [28]. Results presented there, obtained via simulations over datasets including real consumption data from a Greek municipality and real production data from a Spanish renewable energy generation site,[4] indicate that *(i)* the consumption curve can be effectively trimmed and that *(ii)* participating consumers can actually enjoy considerable monetary gains. Specifically, a REScoop that adopts DSM can reduce the daily peak load by 85.99% on average. This is achieved by shifting the consumption of 1.2 MWh and results in almost half the cost per kWh, for consuming this energy during nonpeak hours throughout the day. In more detail, cooperative members that participate regularly, and consistently meet their consumption shifting promises, achieve up to 19.3% monthly bill reductions in a typical industrial case. Highly engaged residential members manage to reduce their monthly bills by 22.67%.

51.5 Conclusions

Providing state-of-the-art scientific solutions to the fledging REScoops industry is key to REScoops' viability and success in meeting their goals, including realizing their anticipated energy efficiency potential. In turn, such a success will be a significant step towards a sustainable energy future. To this end, in this chapter, we identified three axes of scientific research, deriving from various scientific disciplines, which can collectively provide the aforementioned solutions. We demonstrated how solutions linked to these axes can be applied to real-world REScoops' problems and showed that these solutions can actually provide benefits to real-world REScoops and their members. Naturally, there is a great deal of work remaining to be done, in order to improve existing scientific methods and test them in the real-world, even more extensively, and in order to communicate these and related ideas effectively to REScoops and the wider public. In any case, we are convinced that science working hand in hand with the REScoops industry will result to outcomes beneficial to our societies at large.

Nomenclature

AI, MD, GT	Artificial intelligence, mechanism design, game theory
ANOVA	Analysis of variance
DSM	Demand-side management
EE	Energy efficiency
HDD	Heating degree days
ICT	Information and communications technology
REScoop	Renewable energy sources cooperative

[4]The dataset comprised 8000 consumers from Kissamos, Greece, and wind and solar generator production patterns from Galicia, Spain. Please see [28] for more details.

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