D 8.7 POLICY RECOMMENDATION

Project title	**Collaborative Recommendations and Adaptive Control for Personalised Energy Saving**
Project acronym	**enCOMPASS**
Project call	**EE-07-2016-2017 Behavioural change toward energy efficiency through ICT**
Work Package	**WP8**
Lead Partner	**KTU**
Contributing Partner(s)	**All Partners**
Security classification	**Public**
Contractual delivery date	**30/11/2019**
Actual delivery date	**29/11/2019**
Version	**1.0**
Reviewers	**EIPCM, SUPSI**

History of changes

Version	Date	Comments	Main Authors
0.1	20/06/2019	Draft of the deliverable D 8.7 structure	D.Dumciuviene, A. Cibinskiene, M. Andrijauskiene (KTU)
0.11	26/06/2019	Corrections of the draft D 8.7 structure	D.Dumciuviene, A. Cibinskiene, M. Andrijauskiene (KTU)
0.2	15/07/2019	Input in section 1.2.2 and 2.2	C. Schneider (SHF)
0.3	02/10/2019	Corrections of the sections 1.2.1, 1.2.3 drafts	A.Cibinskiene
0.4	17/10/2019	Corrections of the D 8.7 structure	D.Dumciuviene, A. Cibinskiene, M. Andrijauskiene (KTU)
0.5	27/10/2019	Input in sections 1.2.2 and 2.6	C. Schneider (SHF)
0.6	28/10/2019	Input in section 2.6	M. Bertocchi (SES)
0.7	30/10/2019	Input in sections 2.1, 2.2 and 2.4	D.Dumciuviene, A. Cibinskiene, M. Andrijauskiene (KTU)
0.8	31/10/2019	Input in sections 1.2.3,2.3	K.Arvanitis (WVT)
0.9	4/11/2019	Input in section 1.2.1	F. Cellina (SUPSI)
0.91	10/11/2019	Preliminary content check	P. Fraternali (PMI)
0.92	11/11/2019	Preliminary content check	J. Novak (EIPCM)
0.93	15/11/2019	Corrections of the sections 1.1, 2 and 3.	D.Dumciuviene, A. Cibinskiene (KTU)
0.94	19/11/2019	Input to section 2	D. Pueschel (NABU)
0.95	19/11/2019	Bibliography	A. Cibinskiene (KTU)
0.96	21/11/2019	Content refresh of sections 1.2.2 and 3.2.2	L. Albert (SHF) C. Schneider (SHF)
0.97	22/11/2019	Incorporation of Pilot results	D.Dumciuviene, A. Cibinskiene, M. Andrijauskiene (KTU)
0.98	25/11/2019	Revision of section 2 and 3	P. Fraternali (PMI)
0.99	28/11/2019	Revision and quality check	F. Cellina (SUPSI)
1.0	28/11/2019	Revision and quality check	J. Novak (EIPCM)

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723059.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

"D.8.7 Policy recommendations" is specified in the enCOMPASS Description of Action as:

"Policy recommendation to strengthen social and industrial impact of ICT-mediated behavior change tools for energy efficiency, backed from the analysis of the challenges and opportunities of smart metering and community engagement for utilities and public agencies."

This deliverable is one of the outputs of the project task "T8.3 Energy saving guidelines and policy recommendations". This task draws on the outcomes of the regulation watch (T8.1), the pilot results, as well as the business modelling outcomes of Task 8.2, to generate policy recommendations for the EU and for the government bodies at the pilot locations.

The enCOMPASS project experience and the review of the policy evolution over three years, at the European, national and regional level, as well as experiences from related projects were considered to distil the essential challenges of the implementation of behavioral change solutions for energy efficiency and the consequent policy recommendations that would strengthen Europe's capacity to reach the sustainability goals set by the Energy Efficiency Directive and Action Plans.

The effort to abstract from the project experience into a higher-level view of the scientific and industrial landscape of ICT-mediated behavior change tools for energy efficiency has produced the identification of **ten "grand challenges" and ten policy recommendations for addressing such challenges**.

These outcomes reflect the understanding of the Consortium about the critical success factors and risks of ICT-mediated behavioral change systems and, in the intention of the authors of this deliverable, could offer to the European Policy Makers and Funding Agencies a useful insight on the areas where research and policy could act more effectively to achieve the objective of more sustainable development.

This deliverable is organized as follows:

- Section 1 provides an update to the European regulatory framework, which should be read as a follow up with respect to what was already surveyed in *D8.2 Technology, market and regulatory watch report* to provide the overall policy context. A specific focus has been put on the three countries where the pilots have been deployed: Switzerland, Germany and Greece.
- Section 2 looks back at the three years' experience of the Consortium, as well as at the various literature surveys conducted and published during the lifetime of the project, and extracts "**ten grand challenges**", which in the opinion of the Consortium characterize the most critical success factors and risks of ICT-mediated behavioral change systems for energy efficiency.
- Section 3 offers a set of **ten policy recommendations**, which collectively embody the retrospective considerations of the Consortium about which directions could benefit more from a sustained support and promotion by the European Policy Makers, legislators, and Research Funding Agencies.
- Section 4 draws the conclusions: its core contribution is a table that crosses the challenges and the policies, showing that the proposed recommendations have the potential of addressing all the challenges identified by enCOMPASS.

1 UPDATES OF THE REGULATION FRAMEWORK

1.1 PREMISE: WHY BEHAVIORAL CHANGE MATTERS

Environmental changes, such as global warming, climate change, and pollution, are growing in importance among policy makers, environmental practitioners, and researchers. In addition to concerns about increasing economic costs and the environmental effects of energy consumption, research recognizes that buildings and their occupants are resources that could be used to achieve energy-saving targets. Several scientific papers (Mtutu et al., 2016; Altan, 2010; Amunteya et al., 2009; Marcell et al., 2004) focus on the improvement of technical solutions in terms of energy efficiency and, while awareness of the social aspects of energy consumption is increasing (Sovacool et al., 2015), there is still a lack of analyses concerning the behavioral aspects of energy saving and scholars remarked that the combination of technical solutions and behavior insights may lead to better building energy efficiency. Thus, **researching human behavior patterns is becoming essential in solving global environmental problems**. Particularly, scientists underlined the importance of energy-saving behavior in terms of sustainable energy consumption in buildings (Pisello et al., 2016; Manika et al., 2015). Issues and behavior related to energy saving in residential buildings have been widely studied and research conducted in different countries highlighted the key role of public and private sector organizations on energy saving and reduction of CO_2 emissions.

Saving energy in buildings is both a significant challenge and an important opportunity given that the building stock in the world consumes approximately 30 – 40% of the energy (IPCC as cited in Bull et al., 2015) and is responsible for approximately one third of the total green – house gas emissions (GHG). Results of previous studies that focus on the residential sector cannot be used for educational buildings because of different behaviors and intentions to save energy of their occupants. The main differences between residents in residential buildings and occupants in schools, public buildings and offices are on the one side related to the accessibility to energy bills and to the responsibility for their payment; on the other side, they are related to different patterns of use. For example, Pisello et al. (2016, p. 485) mention that “in educational and research buildings occupants spend most of their daytime doing sedentary intellectual activities that require specific indoor comfort conditions”. A field trial of individual energy use in offices (Murtagh et al., 2013) showed that energy use in office computing contributed approximately 30% of energy demand in the European service sector over the last decade. Complimentary research by Mulville et al. (2014) has found much IT office equipment is under-utilised and left on overnight (Bull et al., 2015). Masoso et al. (2010) found that 56 per cent of the total energy in office buildings was consumed during non-working hours simply because occupants left lighting and equipment on at the end of the day. There is high energy saving potential by changing occupant’s use of environmental controls (Yun, Kong, Kim & Kim, 2012). Salleh et al. (2016), Schleich (2009), Yun (2014) state that the energy consumption in public and commercial buildings may be reduced up to 30-40% by behavioral change.

In general, however, consumer behavior plays an important role in saving energy, no matter what sector the consumer represents and which type of building occupant she is. The analysis carried out during the implementation of the project allowed us to identify the critical factors affecting interventions aimed at demand-side management of energy consumption and at appraising the role of proper ICT solutions in processes aimed at promoting behavioral changes.

1.2 THE EUROPEAN UNION POLICY TOWARDS ENERGY EFFICIENCY

The main policy initiative to address this overall challenge has been the drive towards an integrated European Energy Efficiency Policy as a key element on the European Union political agenda.

In 2006 the European Commission published an Action Plan for Energy Efficiency: Realizing the Potential (COM (2006) 0545). Additional energy efficiency standards were laid down in the Energy Performance of Buildings Directive (2010/31/EU). The aim of this Action Plan was to transform the internal energy market into an energy efficient one. In 2011 the European Commission set up a new Energy Efficiency Plan (COM (2011) 0109). The Energy Efficiency Plan 2011 among other issues promotes smart meters and smart grids, expands the National Energy Efficiency Action Plans to cover the entire energy chain and not just energy demand (COM (2011) 0109). In 2012 December the Energy Efficiency Directive (EED) (2012/27/EU) entered into force, requiring Member States to set national indicative energy efficiency targets to ensure that the EU reaches its headline target by 2020. The policy measures that may be used to achieve the savings target include financing schemes and instruments that reduce end-use energy consumption through energy efficient technology, training and education, including energy advisory programmes.

To ensure effective implementation of EED, the Concerted Action was launched in spring 2011, and the 2nd Concerted Action for the Energy Efficiency Directive (CA-EED 2) was launched in 2017. The specific objectives of the Action were to strengthen communication among Member States for effective implementation of the EED (Concerted Action for the Energy Efficiency Directive, Executive Summary Report, 2017). The Action emphasizes measures to facilitate an efficient use of energy by small consumers, including domestic consumers. The focus is on providing continuous information and perform awareness-raising and training initiatives. The document also emphasizes the importance providing citizens with information about the benefits and practicalities of energy efficiency improvement measures (Concerted Action for the Energy Efficiency Directive, Executive Summary Report, 2017).

In 2018 the new amending Directive on Energy Efficiency (2018/2002) (Official Journal of the European Union, 21.12.2018) updated the policy framework to 2030 and beyond. This document set a new energy efficiency target for 2030 of at least 32.5%. The directive highlights the role of economic and/or technological solutions for cost reductions and reinforcement of the energy saving obligations in end use of the 2012 directive. To meet the energy efficiency targets, EU countries will have to reduce their final energy consumption by 0.8% each year for the 2021-2030 period (https://ec.europa.eu/energy/).

The directive entered into force in December 2018. It needs to be transposed into national laws by Member States by 25 June 2020, except for metering and billing provisions, which have a slightly different deadline (25 October 2020). Under the Governance Regulation 2018/1999, Member States are required to draw up integrated 10-year national energy & climate plans (NECPs), outlining how they intend to meet the energy efficiency and other targets for 2030.

Other elements relevant to consumer awareness in the amended directive include:

- Stronger rules on metering and billing of thermal energy, which give consumers - especially those in multi-apartment buildings with collective heating systems – clearer rights to receive more frequent and more useful information on their energy consumption, with the aim of enabling them to better understand and control their heating bills;
- Requirements for Member States to have in place transparent, publicly available national rules on the allocation of the cost of heating, cooling and hot water consumption in multi-apartment and multi-purpose buildings with collective systems for such services;

Updated measures relating to national long-term renovation strategies are now covered under the amended **Energy Performance of Buildings Directive (EPBD)** (EU) 2018/844 - https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/energy-performance-buildings-directive) and, for energy consumers, the **Eco-design Directive** (https://ec.europa.eu/growth/industry/sustainability/ecodesign_en**)**.

The 2018 revision of the European EPBD further promotes smart building technologies, in particular through the Smart Readiness Indicator for buildings (SRI - https://smartreadinessindicator.eu/). This indicator allows rating the capability of buildings (or building units) to adapt their operation to the needs of the occupant, also optimizing energy efficiency, and to adapt their operation in reaction to signals from the grid (energy flexibility). The SRI should raise awareness amongst building owners and occupants of the value behind building automation and electronic monitoring of technical building systems, should give confidence to occupants about the actual savings of those new enhanced functionalities, and ultimately improve the efficacy also of behavioral change approaches such as those pursued in enCOMPASS.

1.3 Updates Of National Initiatives Towards Energy Efficiency

In addition to the activities at the European level, there have been recent developments in the national regulations of the three countries of the enCOMPASS pilots as well. They are described in this section, thus providing an update with respect to the status reported earlier in D8.2.

1.3.1 The case of Switzerland

The most relevant change in the Swiss policy and regulation system refers to the complete revision of the Law on CO_2, which started in late 2016 and was widely discussed in the Parliament throughout 2018 and 2019. The revision of the CO_2 Law is performed with aim of complying with the Paris Agreement and it is likely it will enter into force on January 1st, 2021.

The draft law currently under discussion envisions stricter goals on greenhouse gases emissions, with the final goal of achieving a completely carbon neutral society by the year 2050. By such a year, greenhouse gases emissions by Switzerland are supposed to become zero – and for this purpose, both emissions produced on the Swiss territory, as well as emissions produced abroad for goods and services consumed by the Swiss economy, should be accounted for.

To achieve these ambitious goals, strict measures are envisioned, which either strengthen already existing ones or introduce new ones. In particular, many of the already existing measures are already connected to those developed within the framework of the Swiss "2050 Energy Strategy". Regarding buildings, strict regulations are introduced, imposing that existing buildings emit less than 20 CO_2 kg/m^2 by 2023; additionally, every five years such a threshold is supposed to be decreased by 5 CO_2 kg/m^2. Similarly, stricter emission thresholds are set for vehicles, so that by the period 2020-2024, emissions of new vehicles remain below 95 CO_2 g/km. Also, the levy on CO_2 for fuels consumed by the industry sector and by buildings will be increased, reaching an amount between 96 and 210 Swiss francs per CO_2 ton. Finally, a new taxation on aviation will be activated, with amounts between 30 and 120 CHF per air travel, depending on the class and the travel distance (but excluding transfer flights across Switzerland – namely, such a tax will only be charged on air travel by Swiss citizens).

The earnings from increased taxation will be distributed to the population and the economy, by means of the already existing "Building Programme" (that financially supports energy refurbishing of buildings), direct funding to favour adaptation to climate change, as well as financial support for the diffusion of innovation within society and the economy.

1.3.2 The case of Germany

On May 22/23 2019 the Federal Ministry for the Environment, Nature Protection and Nuclear Safety (BMU) together with the State of Baden-Württemberg and the City of Heidelberg hosted the International Conference on Climate Action (ICCA2019) in Heidelberg, with the objective to support achievement of the objectives of the Paris convention. A significant result of ICCA2019 is the Partnership Declaration on Collaborative Climate Action across all levels of government, whereby states, cities, municipalities, federal states, regions and networks commit to more collaboration, communication and support in the implementation of the Paris Agreement and the UN 2030 Agenda for Sustainable Development and set out priority actions to achieve their respective goals. The declaration was adopted during the high-level round table by representatives of all three levels of government and their networks. (International Conference on Climate Action, 2019)]

The latest public discussion about climate change engaged German politicians to make concrete plans for reaching energy targets before 2050. “Socially acceptable CO_2 pricing” has been discussed in summer 2019 and shall be finally designed before the end of 2019. In February 2019, the BMU sent the draft of a “climate protection law” to the Federal Chancellery for information and early comment and submitted it to the vote on 27 May 2019. The proposal requires that all sectors (e.g., transport, industry, agriculture, energy, buildings) are assigned a fixed saving target and annual reductions in emissions. Each ministry decides on its own responsibility what measures to propose to achieve the required savings. If the target is missed, an immediate recovery programme is to be launched (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2019)

On 09.10.2019, the German Federal Government finally launched the Climate Protection Act with measures to significantly lower CO_2 emissions (50% compared to 1990) by 2030. For six individual sectors, such as transport, agriculture and buildings, the German government is specifying concrete figures on how much CO2 emissions are to fall annually from 2020. Every year, a commission of experts’ reviews whether the targets have been achieved. If this is not the case, the responsible federal ministries must submit an immediate programme within three months to ensure CO_2 reduction (Deutsche Welle, 2019).

In addition, the Federal Environment Ministry promotes effective climate protection measures at the national level through various programmes and projects in municipalities, industry, consumers, schools and educational institutions. The programmes of the national climate protection initiative include, for example, the promotion of (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2019):

- Climate protection in municipalities, social and cultural institutions,
- Innovative individual projects in the fields of business, consumers, education and local authorities,
- Highly efficient small combined heat and power (CHP) plants (mini-CHP) and commercial refrigeration and air conditioning systems.

From several years, Germany has approved a legislation change to enable smart metering in the country. The implementation of Smart Metering must be highly secure, and manufacturers need to go through a complex and challenging certification process. By law, the rollout can only begin when at least “smart meter gateways” of three independent manufacturers are certified. On September 25th2019, the Federal Office for Information Security issued the second certificate based on the protection profile for the Smart Meter Gateway. The **Smart Meter Gateway** will be the central unit of the German measuring system. At this point all connections from inside and outside converge. From the outside, firmly defined market participants such as measuring point operators, electricity suppliers or distribution network operators have access to the gateway. Who gets which access is strictly regulated according to the requirements of the legislator as well as the technical rules of the BSI (Bundesamt für Sicherheit in der Informationstechnik - Federal Office for Information Security). Internally, there are interfaces to the intelligent meters as well as for customers and technicians (VDE FNN (Forum Netztechnik/Netzbetrieb im VDE), 2019).

1.3.3 The case of Greece

Greece is a Mediterranean country with little experience in developing and implementing effective energy efficiency policies and programs, compared with other Organization for Economic Co-operation and Development (OECD) countries. This view has changed during the last few years, as environmental concerns started to drive energy efficiency initiatives and as the effects of EU support for energy efficiency took place. Local businesses are now considering energy efficiency as a viable investment for improving not only energy performance but also their operational efficiency. Despite current uncertainties regarding the Greek economy, it is anticipated that the market in this sector will increase in real terms by 8 - 10% annually over the next three to five years. The ongoing market liberalization in the power sector in Greece and newly available Russian natural gas will most likely drive the growth of relevant energy efficiency programs.

The main pillar of all the efforts towards achieving the energy efficiency target is Directive 2006/32/EC, transposed into Greek legislation by means of Law 3855/2010. Under this Directive, the National Energy Efficiency Action Plans (NEEAPs) provide a framework for the development of a strategy at national level, to further improve energy end-use efficiency through the implementation of concrete measures and policies in the various energy end-use sectors. National EEAPs can be used as an energy policy tool both at Community level, to help extract aggregate and comparative results at EU level, and to contribute in developing a common European energy policy.

The new Law 4342/2015 on energy efficiency sets several other milestones demonstrating the trend of compliance with the recommendations of the EU Directive 2012/27. The first milestone was the definition of the national energy efficiency target. The target was updated to be consistent with the revised national energy strategy for the years up to 2030. More specifically, the energy efficiency target set for 2020 is to achieve final energy consumption levels of 18.4 Mtoe. Under the same Law, among other initiatives, it was decided to renovate 3% of the total floor area of heated and/or cooled buildings owned and occupied by the central government. A list of heated and/or cooled central government buildings with a total useful floor area over 500 m^2 was published in order to attract interested parties.

This section presents horizontal energy efficiency measures, which have been or will be adopted for the implementation of Articles 20 and 21 of Law 4342/2015:

- Information system for monitoring energy efficiency improvement and achieved energy savings.
- Programs to provide financial support for investment in energy-saving technologies and research.
- Tax exemptions on energy savings interventions.
- Bioclimatic upgrades of public open spaces.
- Green rural and island communities.
- Energy Saving.
- Energy Efficiency (Axis 1: Interventions to existing municipal buildings, Axis 2: Interventions to public areas of the urban environment, Axis 3: Interventions in urban transport, Axis 4: Interventions in municipal technical infrastructure, Axis 5: Dissemination, networking and information actions).

Despite the adopted policies, the National EEAPs screening and the expert survey indicate that Greece has neither an ambitious nor an innovative energy efficiency policy. Many aspects of the policy package can still be strengthened. Interim saving targets have been clearly exceeded however the main reason for these energy savings is the economic recession during the reporting periods, which makes it hard to separate the impact of the economic recession and the savings attributable to political measures and policies of NEEAPs.

There is therefore a substantial potential for energy efficiency improvements and renewable energy development in Greece across all sectors of the economy.

2 CHALLENGES AND INSIGHTS FROM BEHAVIORAL CHANGE PROJECTS FOR DEMAND MANAGEMENT

In this section we summarize the challenges and insights gained through a review of the main findings of several behavioral change projects aimed at the reduction of resource consumption. The surveyed projects operated in a variety of settings, including water and energy consumption in households and public buildings. The results of this analysis have been published in (Fraternali et al., 2019).

2.1 FINDINGS FROM EU RESEARCH PROJECTS EXPERIENCE

Several ICT-based interventions targeting behavioural change for resource savings have been recently run throughout Europe, exploiting tools developed on purpose. For instance, Table 1 reports a non-exhaustive list of projects which focused on the reduction of energy (mostly, electricity and gas) and water consumptions.

Table 1 A selection of ICT-based interventions promoting behavioural change for resource saving.

Project	Website	Target Resource	Target group
CHARGED	www.charged-project.eu	electricity and heating	Offices
enerGAware	www.energaware.eu	electricity and heating	Households
ENTROPY	www.entropy-project.eu	electricity and heating	Offices
GAIA	www.gaia-project.eu	electricity and heating	Schools
enCOMPASS	www.encompass-project.eu	electricity	Households, schools, offices
GreenSoul	www.greensoul-h2020.eu	electricity	Offices
ORBEET	www.orbeet.eu	electricity and heating	Offices
PeakApp	www.peakapp.eu	electricity	Households
SmartH2O	www.smarth2o-fp7.eu	water	Households
Social Power	www.socialpower.ch	Electricity	Households
TRIBE	www.tribe-h2020.eu	electricity and heating	Households, schools, offices
PENNY	http://www.penny-project.eu	Electricity	Households

Most of them target public buildings (CHARGED, ENTROPY, GAIA, GreenSoul, ORBEET, TRIBE), e.g. public offices, schools, museums, municipality buildings, universities, and research institutes, whereas others address residential buildings and their inhabitants (enCOMPASS, EnerGAware, Peakapp, SmartH2O, Social Power). All of them but PENNY, which concentrates on the behavioral motivation theory, leverage ICT-based infrastructures for the collection and processing of resource consumption data gathered from smart meters as well as measurement data from heterogeneous sensors, such as presence, movement, luminance, temperature, humidity sensors, or smart plugs. Frequently through ad-hoc middleware solutions, such data is then elaborated by platforms integrating different modules and services. Typically, modeling modules are adopted to reconstruct virtual scenarios replicating the characteristics of the monitored buildings, to run what-if experiments and assess the impact of the application of various resource saving interventions.

Additionally, meter and sensor data are processed to extract knowledge about the activity patterns of the users, which is then used to provide adaptive and contextualized recommendations about possible resource saving actions (enCOMPASS, Charged, GreenSoul, SmartH2O). Such recommendations are typically incorporated in gamified mechanics aimed at raising users' awareness on the importance of reducing consumption and its effects/implications. Different game designs have been tested, ranging from trivia and quiz-like games (SmartH2O, enCOMPASS, GAIA, PeakApp, enerGAware) to strategy-based games (EnerGAware, ENTROPY, TRIBE), and often social-related features such as leader boards (EnerGAware, SmartH2O, enCOMPASS, GAIA) or teams (Social Power) are exploited as well. The underlying design principles have their roots in behavioural sciences and aim at engaging the user in an educational path through the steps of behaviour change (Prochaska et al., 1997), by rewarding her resource saving attitudes. Economic incentives, deriving for instance by the application of dynamic time-of-use tariffs, have also been exploited to induce behavioural changes in energy and water consumption (PeakApp, SmartH2O).

2.2 The Ten Challenges of Behavioral Change Systems for Demand Management

Based on the experience with the above-mentioned projects, gained while either directly running and managing them or interacting with them in H2020 cluster activities, we identified the ten most frequent social, technical, and design challenges, which might affect the effectiveness of demand-side management interventions targeting resource saving: in this deliverable, we use such analysis as the base for providing suggestions to policy makers on how to overcome the social, technical, and design challenges of building demand management systems. As shown by Figure 1, they can be classified in three groups: challenges to be addressed before the start of the intervention, challenges related to the intervention itself, and challenges to be addressed after the intervention.

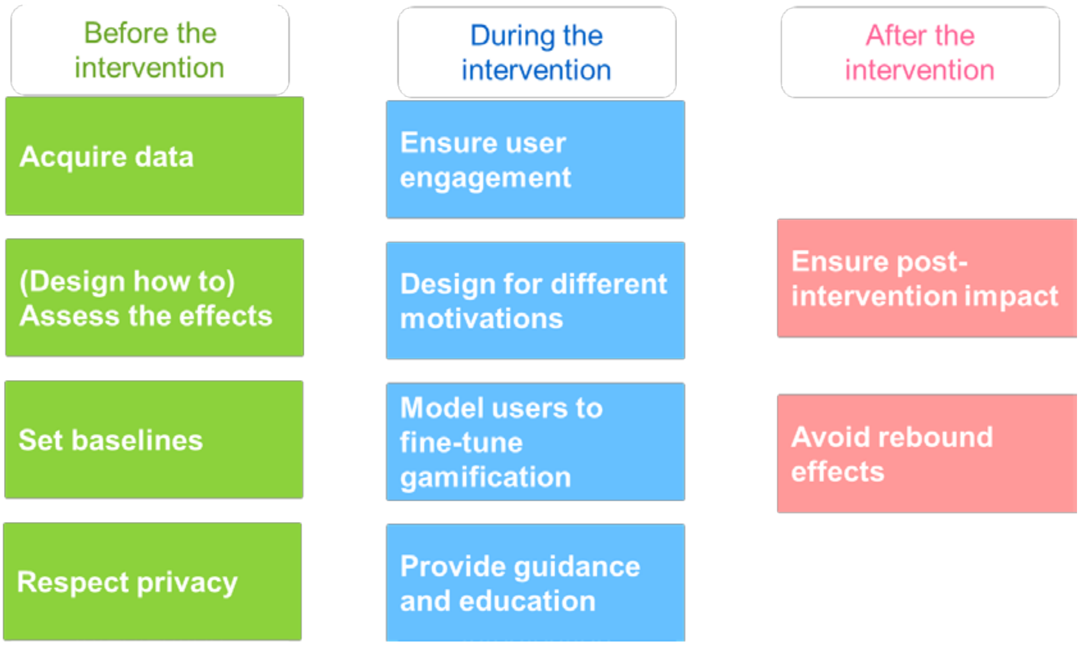

Figure 1: The challenges we identified in demand-side management interventions for behavior change.

2.2.1 Acquiring data

Despite the increasing diffusion of smart digital meters (Fang et al., 2012), data acquisition is still a challenge. Ensuring scalability in the deployment of Automated Metering Infrastructures (AMIs) (Yan et al., 2013), which are expected to span geographically wide regions including millions of inhabitants, involves many practical issues: network coverage and signal transmission quality might be impaired by adverse environmental conditions (especially in rural areas) or achievable only at non-competitive installation costs (Depuru et al., 2011). Moreover, in the case of water resources, most smart meters run on batteries, a fact that imposes limits to the data transmission frequency, and are connected to the data infrastructure of the utility company with *ad-hoc* proprietary networks. Even when an AMI is available, the reception of data is still highly problematic. Errors and delays in data transmission are more the norm than the exception: therefore, the correctness of the metered data must be guaranteed by means of computationally expensive validation procedures, and consumption analytics at individual and aggregated level must be computed to support real-time services (Pitì et al., 2017). Errors or delays in data transmission are extremely troublesome when gamified approaches are exploited: if the system is designed to reward the users' progress on a periodic basis (say, every day), one cannot alter the rules of the games because of missing or corrupted data. Further challenges affect data collection when an AMI is not available and users must voluntarily providing meter readings manually. Since manual data entry has to be systematically repeated over time, it issues challenges about how to guarantee user engagement over time and how to set unbiased baselines.

Manual data collection is a well-known and problematic aspect of system design, as demonstrated by the few efforts in this direction (e.g. the Munx system in Switzerland, Munx.ch). In fact, first of all users are requested an effort, for which they need to be somehow rewarded. As a possible rewarding strategy, prizes might be raffled out among all those who have regularly introduced their data, so that their baseline can be computed. Alternatively, building of the baseline might be included in the gamified activities, by attributing virtual rewards to the users who manually enter enough consumption data.

2.2.2 Assessing the effects

If a statistically sound analysis of the effects of the demand-side-management programme is envisioned, whenever possible an experimental design (randomized controlled trial) has to be adopted, or at least a quasi-experimental one (Vine et al., 2014; Frederiks et al., 2016). This implies that both a treatment and a control group must be activated, and a comparison of the after/before resource-consumption behaviour of both the treatment and the control group has to be performed. Recruitment of the control group must be carefully planned, to avoid any unintentional influence on the behaviour of the group members, by the above-mentioned Hawthorne or "social approval" effects. If the demand-side-management programme addresses a centralized-distributed resource, the easiest way to access control group consumption data would be to unobtrusively access historical consumption data of a comparable group of target users, already collected and stored by the utility company. This would not allow a randomized controlled trial, since no random assignment to the control or the intervention group would have been possible, thus reducing the effort to the status of a quasi-experiment; however, this procedure would avoid introducing any biases in the control group consumption data. To guarantee privacy regulations are respected, users in the control group would however need to explicitly provide the utility company with informed consent to access their sensible consumption data.

2.2.3 Setting baselines

Baseline data may be used both directly within the demand-side-management tool, to show user progress with respect to her initial average behaviour, and to assess effectiveness of an intervention, through a before/after comparison of data collected in *similar* conditions. Collecting reliable baseline data requires long period of times, enough to account for a wide variability in the independent variables that might affect consumption patterns, such as the weather conditions, the length of the day, the day of the week, or the month of the year. However, if hypotheses can be made regarding variables such as the season of the year, ensuring similar conditions for variables such as "household composition" or "household equipment of electric appliances" is much more challenging, since these variables cannot be controlled, when the demand-side-management interventions are lead in real-life settings.

Baseline setting is further challenging when AMIs are not available and users are requested to manually enter their meter readings. The data entry activity might in fact introduce two types of biases impairing reliability of the gathered baseline. First, an "Hawthorne effect" might take place - which happens when users alter their behaviour towards a more socially desirable one (lower energy consumption than usual), due to awareness of being observed (Adair, 1984; Adams et al., 2005; Nichols et al., 2008; Tiefenbeck, 2016). Second, regular data entry might act as an unintended feedback on their consumption patterns, and thus start to actively persuade them to change their behaviour, thus impairing reliability of baseline values.

2.2.4 Respecting privacy

The drawback of collecting fine grained consumption data and of applying NIALM techniques is the exposure of users to potential privacy breaches: though the information obtained via disaggregation approaches can lead to useful insights on individual energy usage habits, it can also be exploited by unauthorized entities to learn potentially sensitive details such as household occupation periods, number of occupants, cooking, or sleeping patterns (Yan et al., 2012). This would potentially lead to harmful consequences, e.g. burglars attempting robberies when houses are sensed as unoccupied or companies designing targeted marketing campaigns based on individual usage statistics. To avoid such drawbacks, several technical solutions have been proposed, ranging from privacy-preserving cryptographic protocols for metering data collection to mechanisms based on noise injection and techniques which intelligently exploit the charge/discharge cycles of a locally installed battery to alter the individual consumption patterns (Rottondi et al., 2013). Among such solutions, only the latter two ensure compatibility with the application of NIALM algorithms, however at the price of reducing their effectiveness due to the induced distortions in the metering data, if no proper aggregation techniques are exploited (Rottondi et al., 2013; Chen et al., 2018).

2.2.5 Ensuring engagement

The most challenging task of a socio-technical system involving people on a voluntary basis is engagement. First, this requires to address a recruitment problem and to get people use the demand-side-management tool; then, one must address how to maintain their engagement over time.

Recruitment of the participants to demand-side management interventions is usually performed by means of public advertising and communication activities, through flyer distribution, traditional mass media and social networks (self-selection recruitment strategies). In such voluntary opt-in frameworks, it is likely that individuals with higher environmental awareness and pro-environmental attitude are stimulated to join the tool, while “mainstream” citizens are more likely to ignore the invitations (Hartman, 1998; Tiefenbeck et al., 2019). To reduce this self-selection bias, “opt-out” frameworks should be preferred, for example by involving municipal authorities or utility companies to formally notify possible users they have been selected to join an innovative demand-side-management programme. This would imply that all target groups are by default enrolled in a programme, from whom they are requested to formally withdraw, if they are not interested in participating (Pichert et al., 2008; Frederick et al., 2016). Such an approach would, however, not definitively solve the problem, since no obligations to join behaviour change programmes can be forced. A further way to raise the interest of “mainstream citizens”, that however still needs to be supported by sound experimenting in the field, would be to offer real-life rewards. Since use of extrinsic motivational factors is controversial (Deci, 1971), prizes could at first be exploited to engage people with low intrinsic motivation for change, and later on could gradually be replaced by less tangible, intrinsic motivational factors, as long as people get engaged by the programme (Ryan et al., 2000).

Once the challenge of engaging people has been addressed, the problem remains about how to maintain engagement over time. Attempts to promote individual behaviour change by means of ICT-based interventions might in fact be affected by high drop-out rates, such as for instance in the Social Power intervention, within whom 40% of participating households dropped out of a three month app-based gamified intervention (Wemyss et al., 2019). A strategy to maintain users engaged for longer periods might be to leverage social relationships, building on already existing, real-life relations within a community and blending the behavioural change messages and programmes seamlessly in their activity. For example, within citizen science processes, very large and active trekking and mountaineering groups are engaged in data collection for climate change impact monitoring. Similarly, targeting members of a community such as a school, a company, or even a sport club (e.g., work colleagues, class mates and their families, etc.) could favour a larger diffusion of the impact of behaviour change initiatives: exploiting the network of formal relations of individuals within their community is expected to help creating a stronger commitment for participants, to remain active until they manage to adopt new consumption patterns (Frick et al., 2017). Another strategy might be to opt for opening-up the design of the intervention main contents and activities to the citizens themselves, in a living lab-style co-creation collective effort (Pallot et al., 2010). The underlying hypothesis being that, if they own the intervention, individuals will be stimulated to remain active for a longer period of time and promote it among their circle of family and friends. Evidence of effectiveness of both the above mentioned strategies (anchoring to real life relations and favouring co-creation) is however still to be collected. Therefore, how to maintain user engagement over time remains an open challenge.

2.2.6 Designing for different motivations

Designing an effective behavioural change system requires that the adopted strategies for stimulating awareness and engagement (e.g. through visualization of consumption and gamification) address a wide group of potential users, with different motivations and affinities. Catering to a heterogeneous group of users poses a range of design challenges. On one hand, different users have different environmental goals and values (Lindenberg et al., 2007), as well as different needs with regard to energy consumption feedback, among others because users differ in terms of their behavioural change progress. Second, the structural characteristics of energy consumption behaviour as abstract, non-sensory, comprised of multiple behaviours, and of low personal relevance to most individuals (Karlin et al., 2015) pose challenges on the designers of energy consumption visualizations, among which representation of energy data in meaningful units, as well as the temporal grouping of data (e.g real-time, by day, week or month). For example, previous research has demonstrated that the abstract units commonly used for energy consumption (e.g. kWh) are difficult to understand for household users (Karjalainen, 2011). To address this, a metaphor-based visualization approach (e.g. eco-visualizations that map energy consumption to objects from nature) can help users cope with the cognitive load of interpreting complex numerical and abstract information.

One strategy to account for such differences is to provide multiple layers of detail and representations of the consumption feedback, to allow users with different data affinity and intrinsic or extrinsic motivations to switch between views that best fit their needs. Also, alternative metaphors that map the consumption from kWh to different types of visualizations can be used reduce the cognitive load inflicted on the user, and to facilitate comprehension. Determining which types of metaphors to use can be based on key motivational drivers, such as those provided by the goal framing theory, that distinguishes between egoistic values (e.g. money), altruistic values (e.g. environmental values) and hedonic values (e.g. gratification, fun).

Similarly, while some users are motivated more by intrinsic drivers, others will be more responsive to extrinsic incentives (e.g. the prospect of winning prizes or rewards). Applying competitive or collaborative mechanisms as a stimulus for user engagement will also provide different results depending on how well different users respond to the one or the other. While introducing competition to motivate engagement is widely spread in gamification approaches, some contributions from related domains (e.g. stimulating water saving) recommend making competition optional and stressing collaboration instead (Froehlich et al., 2012). Different user types may also place different importance on the pragmatic affordances of a system (i.e., its practical usefulness and functionalities), whereas others my place a higher value on hedonic affordances (e.g. the systems attractiveness, its visual design, joy of use etc.) (Venkatesh et al., 2012). Accordingly, a well-designed behavioural change system should combine a spectrum of incentives and design elements that address multiple motivational drivers and preferences of different types of users.

2.2.7 Modeling users to fine tune behavioral stimuli

A cornerstone of behavioral change through gamification is observing users' actions, computing achievements (e.g. verifying if a saving goal was met) and acknowledging them with a reward (e.g. a virtual one, such as a badge or a status promotion, or a real one, such as a prize or a discount). Achievements are quantified with points, which serve the purpose of reducing heterogeneous actions to a common metrics, enabling comparison, competition and rewarding. A critical issue in the design of a gamified mechanics is the assignment of points to actions; in presence of an ample spectrum of actions, that can be performed by users with different capabilities and living in different contexts, deciding the right amount of points for each action deeply influences the dynamics of the whole system and can emphasize alternative aspects of the user's response, possibly determining the ultimate impact on behaviour (Scheider et al., 2019). To this aim, agent-based modeling (Zheng et al., 2014) can help understand the dynamics of the socio-technical system and predict its behaviour, under different point assignment schemes.

Several research efforts have been devoted to Non-Intrusive Appliance Load Monitoring (NIALM), which aims at decomposing the aggregate household energy/water consumption data collected from a single measurement point (e.g. the smart meter installed at the customer's premises) into device-level consumption data (a thorough survey is found in (Zoha et al., 2012; Cominola et al., 2015). Such disaggregated information can be exploited to refine the rewarding mechanisms, by targeting energy saving actions at the individual appliance level. Disaggregation can be facilitated by the installation of sub-metering devices such as smart plugs or sensors on-device, which track the individual consumption patterns of the main electrical/water appliances, or of light/presence/temperature sensors, which enable the analysis of correlation between energy/water consumption events (Zoha et al., 2012). Though most of state-of-the-art methods are capable of accurately estimating the average fraction of energy/water consumed by each appliance, the reconstruction of individual consumption patterns is much more problematic, thus limiting the potential feedback that could ideally be inferred by such knowledge. This is especially true if the granularity of the metered data is coarse (e.g. one sample every 15 or 60 minutes, which represent the most commonly adopted standards in current smart metering systems). Indeed, most of the approaches investigated by the scientific community assume that consumption data at minute (or even sub-minute) granularity are available. Moreover, stimulating behaviour change effectively requires visualization of NIALM outputs that is easily understandable at a glance and seamlessly embedded into user's context, offering details and comparisons based on the current activity situation, and relating it to possible energy saving actions. Closing this loop effectively in a user-friendly way is still an open challenge.

2.2.8 Providing guidance and education

Behavioural change schemes based on gamification assume that an engaged user is triggered towards a more sustainable pattern of consumption. However, such a transition may require knowledge not fully possessed by the user about the best way to improve consumption. Therefore, the need arises to blend educational content (e.g. how-to videos, resource saving tips and recommendations) within the consumption visualization and gamification approach. On one side, educational materials can be juxtaposed to other behavioural change stimuli, in the hope that the activated user, motivated by gamification incentives, takes the time to explore them. A more integrated approach injects educational hints into the very core of the gamification elements. For example, SmartH2O (Novak et al., 2018) exploits the synergy between a card-based board game named "DROP! The question", a gamified online portal, and a mobile application, to trigger behavioural changes in water conservation attitudes of users.

Another example of close integration between learning and gamification elements is provided by the *Social Power* app, which targets reduction in household electricity consumption (Wemyss et al., 2018). Every week, the app launches thematically focused tips and challenges, as step-by-step guides to support households in changing their patterns of use of appliances. Each time a challenge is completed, users are rewarded with points, so that such a positive reinforcement increases their intention to adopt the behaviour in the feature and make it a new habit (Kurz et al., 2015). Such an action-oriented, gamified learning approach provides a model of learning that occurs simply by doing sustainable activities within real-world.

2.2.9 Ensuring post-intervention impact

A demand-side management programme may produce its expected outcome and the adoption of less resource-intensive consumption patterns. However, the challenge remains for the intervention to create new enduring habits, and not just a short-term effect (Allcott et al., 2014). Only a few studies monitored the effects of resource-saving interventions long after their conclusion, and there is not enough evidence to generalize their results and assess long-term effectiveness of different types of interventions. For instance, (Hargreaves et al., 2013) and (Schleich et al., 2017) came to opposite conclusions, regarding long-term effects of similar electricity-saving interventions, consisting in endowing households with in-home displays of electricity consumption and providing them with a feedback. The former (Hargreaves et al., 2013) reports that the statistically significant effects produced by the intervention in the short-term tended to disappear in the long-term, namely one year after the intervention itself, since the information provided by the display was quite consistent, thus providing no new motivation and input to save electricity. Instead, for a similar 11-month long intervention with households, the latter (Schleich et al., 2017) reports statistically significant long-term savings. More recent research found that positive effects on long-term energy consumption could be produced, provided that normative feedback messages are continued over time (Anderson et al., 2017). Such results can be framed within the trans-theoretical model of behaviour change (Prochaska et al., 1997), according to which behaviour change occurs through progression by a series of stages: as long as individuals practice with the implementation of the new behaviour, they enter the maintenance stage, during which the need for external support progressively decreases, they are less tempted by relapse and are more confident that they can regularly put the new behaviour into practice. However, relapse is always possible, therefore specific actions need to be activated to avoid it, just like during the intervention itself. Empirical experience reported above teaches us that, though probably necessary, providing visualization of one's own resource consumption is generally not enough to maintain the positive short-term impacts over time. Additional motivational elements, as also suggested by (Prochaska et al., 1997; Wemyss et al., 2019; Ohnmacht et al., 2017), might be continuing push-notifications about resource-saving challenges or tips, or offering comparative feedback possibilities with similar households, thus embedding the feedback information in the real-life social context of the users, even better if also exploiting pre-existing channels (Breukers et al., 2013).

2.2.10 Avoiding rebound effects

Even when demand-side-management programmes maintain their long-term effectiveness, one cannot exclude that they indirectly produce increases in resource consumption, by the so-called "rebound effect" (Greening et al., 2000). Rebounds can in fact take place either directly, if lower billing costs lead individuals to increase consumption of the resource itself, or indirectly, if individuals realize they can invest the saved money in other resource-intensive products and services, such as a new tablet or an overseas holiday. Depending on the type and duration of the demand-side management programme, rebounds can already start occurring during the intervention or only appear once it has ended, especially for indirect rebounds and if households receive summary evaluations of their performances, for example through home energy reports (Allcot, 2011). In the worst case, such induced increases in consumption might be so high, that they would over-compensate the savings induced by the demand-side management programme, and the overall resource consumption would turn out to be larger at the end of the programme, than before its start (backfire effect). Even though the amount of rebound effects affecting an intervention are still questioned (Gillingham et al., 2013), framing a resource-saving intervention within a wider environmental, climate and energy awareness and education programme might help limiting its rebound perverse effects.

3 POLICY RECOMMENDATIONS

We have identified the ten most recurrent and critical challenges affecting ICT-based eco-feedback and gamification programmes targeting resource saving. Drawing from practical experience in a number of real-life interventions, we advanced recommendations to address them and identified topics requiring further investigation. Summarizing the lessons learnt from these experiences, and considering the remaining open challenges, we conclude by sketching an agenda for policy makers and researchers aimed at supporting individuals towards more sustainable resource consumption patterns.

3.1 USER EMPOWERMENT

Favour direct data exposure to the users to foster individual responsibility and enhance privacy.

Most consumer engagement projects depend on utility companies to access consumption data and give such data back to the users, who in principle are the legitimate owners. Ways should be explored to empower the consumers to see their own data directly, without dependency on the utility companies, in a more "do-it-yourself" manner. By **promoting the design of innovative smart metering devices** that comprise user interfaces or can **display high frequency metering data directly on the consumers' devices** (e.g. on their smartphones), consumer engagement apps would not need to depend on data exported outside the users' premises, thus reducing privacy risks. This policy is orthogonal and does not necessarily collide with the need of data consolidation and multi-tenancy (see later recommendation), which can focus on mid-frequency, anonymised data consolidation for demand management by utilities and distributors.

3.2 HIGH RESOLUTION IS KEY

Support the deployment of a reliable and secure high capacity data transmission infrastructure throughout Europe.

Behaviour change systems are heavily dependent on mid-to-high frequency data about the consumption behaviour. Scaled to the whole European scenario, this requirement demands a massive deployment of high capacity and reliable telecommunications. Promoting **resource consumption data collection as a principal use case for the deployment of 5G telecommunications** will accelerate the transition to trustable behavioral systems based on accurate consumption data. In parallel, it will foster a better awareness by citizens of the balance between the ecological impact of the 5G telecommunications deployment and the environmental benefits that a proper use of such an infrastructure can produce towards more trustable and accurate consumption feedback and behavioral change systems.

3.3 INFRASTRUCTURE STREAMLINING AND STANDARDIZATION

Promote Europe-wide standardization and certification of the entire energy data collection chain.

Smart meter and AMI infrastructure deployment is progressing fast throughout Europe. In this phase, member states have variable levels of technological maturity and the market of smart metering, AMI solutions, and connectivity infrastructure is booming with an unprecedented variety of solutions. However, such a thriving market has also the potential downside of creating unnecessary technical heterogeneity, which in turn produces software and data integration difficulties, due to the proliferation of *de facto* standards pushed by the industry alone. A European effort towards **establishing a shared technological reference framework** and **implementation guidelines** for both energy production, transport, distribution and measurement tiers and for the building energy efficiency assessment and improvement will help the market transition to a maturity level, where system and data operability come to a lesser cost. Initiatives such as **German Smart Meter Gateway** certification programme are steps in this direction. The mentioned Energy Performance of Buildings Directive and the **Smart Readiness Indicator for Buildings** are other examples that pursue this goal.

3.4 HOLISTIC ENERGY DEMAND AND PRODUCTION INTEGRATION

Support the combination of production and consumption in behavioural change.

Many demand management and engagement techniques leverage the ecologic attitude of consumers, who engage based on their willingness to contribute to environmental conservation. As renewable energy becomes more and more available to users, also at the level of self- and micro-generation, a new approach to consumer engagement should **merge demand-side and production-side management**. Users could be rewarded not only for the way in which they reduce consumption, but also for their commitment to clean energy production, according to the "prosumer" concept (Parag et al., 2016), or for rethinking their consumption practices in order to reduce the load on the grid. Such a joint approach to engagement could greatly increase the impact of behavioural change applications, because a broader spectrum of stimuli could be exploited. This would also expand the reach of such schemes, which are being experimented within a few national contexts (e.g. Germany or Switzerland), thus producing a greater impact at the global scale.

3.5 DATA CONSOLIDATION AND MULTI-TENANCY

Support a pan-European, cross-domain consumption data repository.

Collecting accurate data in a reliable, secure, and privacy-preserving way is a key achievement to enable the empowerment of citizens through better data availability and transparency and the development of novel methods for managing the entire energy lifecycle, through better prediction, monitoring and reaction. However, this effort can be pursued neither by single utilities alone nor by individual countries: it is a European level goal. Data collection needs to be standardized, treated for security and anonymity, consolidated in a **multi-tenant European repository, made available in a secure and privacy-preserving way to all the actors of the energy chain**: citizens, utility companies, distribution system operators, technology providers, infrastructure managers, and last but not least researchers. Initiatives such as the Finnish Data Hub (https://www.fingrid.fi/en/services/information-exchange-services/datahub/) are examples that point in such a direction. Therefore the recommendation to policy makers is: making Europe the first entity that creates, publishes, and exploits a continental-scale secure, privacy-respecting data hub of the metered resource consumption that demonstrates that mass-scale data collection can be done for the benefit of the whole society and in full respect of the citizens' data rights.

3.6 OPEN DATA AND OPEN CONTENT

Promote an open European repository of behaviour change resources for researchers and practitioners.

Behavioural change applications require not only the availability of consolidated consumption data but also the collection of content to address the consumers: questionnaires, educational videos, tips, stories, trivia, etc. Projects tend to develop such valuable resources independently. A coordinated action could be promoted throughout Europe in order to **build a unique open repository of European resources**, easily translatable in all the languages of the European Union, so to reduce the cost and time to market of behavioural change solutions. This initiative would build a body of knowledge at the European level and make project efforts more uniform and thus comparable.

3.7 LIFE MOTIVATORS

Encourage research and practice on multi-domain behavioural change and life motivators.

Behavioural change applications targeting individual consumption reductions could approach the consumption of multiple resources, e.g. electricity, gas and water, in a holistic manner. The ideal approach would be to design "**better life motivators**" for individuals, addressing all the aspects in which they can make a contribution (energy and water consumption, mobility, production, circular economy, waste, etc.). This would increase the global impact of the intervention, allowing the recommendation of actions that benefit more than one aspect and also favouring positive spill over effects (Truelove et al., 2013). Also, the effort of developing behavioural change apps and platforms would be better justified by the application to multiple domains.

3.8 EDUCATION

Leverage schools as game-changers.

As the Greta Thunberg phenomenon has recently demonstrated, young generations have an enormous potential to act towards the achievement of the Sustainable Development Goals and can exercise an effective pressure on policy makers. As also the activities of the enCOMPASS project has demonstrated, schools are more than eager to cooperate in pro-environment initiatives and **pupils and teachers are the natural candidates to the role of ambassadors of behavioral change**. Such power should be harnessed at the continental level, by promoting pan-European school cooperation schemes, in the spirit of an **Erasmus Program for the Planet**, which could focus student mobility and school exchange of experience with a specific focus on sustainable development goals.

3.9 SMART ENERGY IN A SMART CITY

Consider behavioral change for energy sustainability as a component of a broader effort towards sustainability of future smart cities.

Sustainability cannot be confined to a single aspect of people's life and more than half of the world's population live in urban areas, increasingly in highly-dense cities. Therefore, both behavioral and technological interventions towards energy efficiency should be framed in the broader scope of smart cities initiatives. Smart cities initiatives could provide a backdrop for promoting "life motivators" and for implementing a cross-cutting approach to behavioral change, **addressing not only the consumers' attitude towards energy saving, but more generally all the facets of "citizenship"**. Such holistic approach should address in a consistent manner resource consumption (water, energy, gas), mobility, health, nutrition and lifestyle, workplace practices, education and social participation. In this way behavioral change stimuli could benefit from an amplification effect thanks to the interaction of different behavioral determinants and the policies towards efficiency and sustainability could benefit from the economy of scale of addressing the multiple aspects of "sustainable citizenships" in a coordinated manner.

3.10 LONG-TERM SUPPORT TO BEHAVIORAL RESEARCH

Promote and support longitudinal studies and research over time.

Demand-side management programmes have a necessarily limited life-cycle (typically three years). Behavioural change processes, however, demand a sustained effort, to first collect meaningful and reliable baselines and then to observe impacts over long periods of time, such as a decade. Thus, long-term funding schemes should be created, to allow **maintaining ICT demand-side management platforms and interventions over longer periods of time**. This type of research is essential to understand the long-term effect of behavioral intervention and sturdy rebound effects that may appear also long after the intervention. A pan-European initiative to support long-lasting, mid-term, future-oriented research efforts at continental scale on multiple sustainability goals would give Europe greater insights on the social and technical factors affecting the success of behavioral change systems.

4 CONCLUSIONS AND FINAL RECOMMENDATIONS

In this deliverable the enCOMPASS Consortium has distilled the high-level insights gained in multiple years of research and practice in the design deployment and evaluation of demand management system based on behavioral change. In retrospective, **ten “grand challenges”** that affect the success of such a category of systems have been identified, which span all the prominent socio-technical aspects of this complex category of solutions.

The Consortium has also strived to generalize the project experience and produce a set of **ten policy recommendations** that, in the opinion of enCOMPASS participants, could help Europe to face the challenge of the transition towards a more sustainable society.

The contribution of this deliverable is obviously non-exhaustive and somehow “biased” by the focus of the enCOMPASS project on behavioral change through smart data collection, visualization and contextual recommendations. More insight for policy making can be elicited by research oriented toward the economic dimension of energy saving, e.g., to distil policy making guidelines that focus on flexible resource pricing, economic incentives and other similar interventions.

As a conclusive contribution, Table 1 summarizes the ten challenges and the ten policy recommendations distilled by the enCOMPASS project in its activity and in the survey of the relevant international research efforts and best practice. As the table shows, implementing the proposed policies has the potential of addressing all the ten identified challenges.

Table 1 Ten Policies for Ten Behavioral Change Challenges

	User empowerment	High resolution is key	Infrastructure streamlining and standardization	Holistic energy demand and production integration	Data consolidation and multi-tenancy	Open data and content	Life motivators	School as ambassadors	Smart energy in a smart city	Long-term support to behavioral research
Acquiring data	X	X	X		X	X				
Assessing the effects					X	X				X
Setting baselines					X	X				
Respecting privacy	X				X					
Ensuring engagement	X					X				
Designing for different motivations				X			X		X	
Modeling users to fine tune gamification	X	X		X	X					
Providing guidance and education						X		X		
Ensuring post-intervention impact	X			X						X
Avoiding rebound effect	X			X						X

5 REFERENCES

Action Plan for Energy Efficiency: Realizing the Potential (COM(2006) 5045 final).

Adair, J.G. The Hawthorne effect: a reconsideration of the methodological artifact. Journal of applied psychology, 69(2):334, 1984.

Adams, S.A., Matthews, C.E., Ebbeling, C.B., Moore, C.G., Cunningham, J.E., Fulton, J., Hebert, J.R. The effect of social desirability and social approval on self-reports of physical activity. American journal of epidemiology, 161(4):389–398, 2005.

Altan, H. Energy efficiency interventions in UK higher education institutions. Energy Policy, 38(12):7722–7731, 2010.

Allcott, H. Social norms and energy conservation. Journal of public Economics, 95 (9): 1082-1095, 2011.

Allcott, H., and Rogers, T. The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. American Economic Review, 104(10): 3003-37, 2014.

Amutenya, N., and Shackleton, CM., and Whittington-Jones, K. Paper recycling patterns and potential interventions in the education sector: A case study of paper streams at Rhodes University, South Africa. Resources, Conservation and Recycling, 53(5): 237-242 ,2009.

Anderson, K., Song, K., Lee, S., Krupka, E., Lee, H., Park, M. Longitudinal analysis of normative energy use feedback on dormitory occupants. Applied energy, 189:623–639, 2017.

Breukers, S., Mourik, R., DuneWorks, B. The end-users as starting point for designing dynamic pricing approaches to change household energy consumption behaviours. Report for Netbeheer Nederland, (DuneWorks, Eindhoven), 2013.

Bull, R., Lemon, M., Everitt, D., & Stuart, G. Moving beyond feedback: Energy behaviour and local engagement in the United Kingdom. Energy Research & Social Science, 8:32–40, 2015.

Chen, Y., Martinez, J.-F., Castillejo, P., Lopez, L. A privacy-preserving noise addition data aggregation scheme for smart grid. Energies, 11(11):2972, 2018.

Cominola, A., Giuliani, M., Piga, D., Castelletti, A., Rizzoli, A.E. Benefits and challenges of using smart meters for advancing residential water demand modeling and management: A review. Environmental Modelling & Software, 72:198–214, 2015.

Concerted Action for the Energy Efficiency Directive. Executive Summary Report. CA-EED. 2017

Deci, E.L. Effects of externally mediated rewards on intrinsic motivation. Journal of personality and Social Psychology, 18(1):105, 1971.

Depuru, S.S.S.R., Wang, L., Devabhaktuni, V. Smart meters for power grid—challenges, issues, advantages and status. In 2011 IEEE/PES Power Systems Conference and Exposition, pages 1–7. IEEE, 2011.

Eco-design Directive. *DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products(recast).* Retrieved November 15, 2019 from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009L0125-20121204

enerGAware. (n.d.).Retrieved October 14, 2019 from: https://www.energaware.eu

Energy Performance of Building Directive. (n.d.). Retrieved November 11, 2019 from: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/energy-performance-buildings-directive

EUR-Lex. (2019). Governance of the Energy Union. Retrieved October 15, 2019 from: https://eur-lex.europa.eu/legal-content/EN/LSU/?uri=uriserv:OJ.L_.2018.328.01.0001.01.ENG

European Commission. (2019). *Energy Efficiency Directive (EED) (2012/27 / EU).* Retrieved October 20, 2019 from: https://ec.europa.eu/energy/en/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-directive

European Commission. (2019). *Energy Performance of Buildings Directive (2010/31 / EU).* Retrieved October 20, 2019 from: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/energy-performance-buildings-directive

European Environmental Agency. (n.d.). *Energy Efficiency Plan (COM (2011) 0109).* Retrieved October 20, 2019 from: https://www.eea.europa.eu/policy-documents/com-2011-109-final-energy

Fang, X., Misra, S., Xue, G., Yang, D. Smart grid—the new and improved power grid: A survey. IEEE communications surveys & tutorials, 14(4):944– 980, 2011.

Forum Netztechnik/Netzbetrieb im VDE. (2019). *Smart-Meter-Gateway: Die Zentraleinheit des intelligenten Messsystems*. Retrieved November 17, 2019 from: https://www.vde.com/de/fnn/arbeitsgebiete/imesssystem/lastenhefte/smart-meter-gateway

Fraternali, P., Cellina, F., Gonzales, S. L. H., Melenhorst, M., Novak, J., Pasini, C., Rottondi, C. and Rizzoli, A. E. Visualizing and gamifying consumption data for resource saving: challenges, lessons learnt and a research agenda for the future. Energy Informatics, 2(1):1–13, 2019.

Frederiks, E.R., Stenner, K., Hobman, E.V., Fischle, M. Evaluating energy behavior change programs using randomized controlled trials: Best practice guidelines for policymakers. Energy research & social science, 22:147–164, 2016.

Frick, V., Seidl, R., Stauffacher, M., Moser, C. Promoting energy-saving behaviour: Formal social groups as promising middle actors for municipal interventions. Energy Efficiency, 10(6):1539–1551, 2017.

Froehlich, J., Findlater, L., Ostergren, M., Ramanathan, S., Peterson, J., Wragg, I., Larson, E., Fu, F., Bai, M., Patel, S., et al. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. In Proceedings of the SIGCHI conference on human factors in computing systems, pages 2367–2376. ACM, 2012.

GAIA. (n.d.). Retreived October 10 from: https://www.gaia-project.eu

Gillingham, K., Kotchen, M.J., Rapson, D.S., Wagner, G. Energy policy: The rebound effect is overplayed. Nature, 493(7433):475, 2013.

Greening, L.A., Greene, D.L., Difiglio, C. Energy efficiency and consumption—the rebound effect—a survey. Energy policy, 28(6-7):389–401, 2000.

GreenSoul. (n.d.). Retrieved October 11 form: https://www.greensoul-h2020.eu

Hargreaves, T., Nye, M., Burgess, J. Keeping energy visible? exploring how householders interact with feedback from smart energy monitors in the longer term. Energy policy, 52:126–134, 2013.

Hartman, R.S. Self-selection bias in the evolution of voluntary energy conservation programs. The Review of Economics and Statistics, pages 448–458, 1988..

Karlin, B., Zinger, J.F. and Ford R. The effects of feedback on energy conservation: A meta-analysis. Psychological Bulletin, 141(6):1205, 2015.

Karjalainen, S. Consumer preferences for feedback on household electricity consumption. Energy and buildings, 43(2-3):458–467, 2011.

Kurz, T., Gardner, B., Verplanken, B., Abraham, C Habitual behaviors or patterns of practice? explaining and changing repetitive climate-relevant actions. Wiley Interdisciplinary Reviews: Climate Change, 6(1):113–128, 2015.

Lindenberg, S., Steg, L. Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social issues, 63(1):117–137, 2007.

Manika, D.; Gregory-Smith, D.; Wells, V.; Graham, S. Home vs. workplace energy saving attitudes and behaviors: the moderating role of satisfaction with current environmental behaviors, gender, age, and job duration. In Proceedings of AMA Winter Marketing Educators' Conference 2015: Marketing in a Global, Digital and Connected World, USA, 2015.

Marcell, K.; Agyeman, J.; Rappaport, A. Cooling the campus: Experiences from a pilot study to reduce electricity use at tufts university, usa, using social marketing methods. International Journal of Sustainability in Higher Education, 5(2):169–189, 2004.

Masoso, O. T., & Grobler, L. J. The dark side of occupants' behaviour on building energy use. Energy and buildings, 42(2):173–177, 2010.

Mtutu, P.; Thondhlana, G. Encouraging pro-environmental behaviour: Energy use and recycling at rhodes university, south africa. Habitat International, 53:142–150, 2016.

Mulville, M., Jones, K., & Huebner, G. The potential for energy reduction in uk commercial offices through effective management and behaviour change. Architectural Engineering and Design Management, 10(1-2):79–90, 2014.

Munx, the energy efficiency portal. https://munx.ail.ch/

Murtagh, N., Nati, M., Headley, W. R., Gatersleben, B., Gluhak, A., Imran, M. A., & Uzzell, D. Individual energy use and feedback in an office setting: A field trial. Energy Policy, 62:717–728, 2013.

Nationale Klimaschutzinitiative. (n.d.). *Klasse Klima - Her mit der coolen Zukunft!*. Retreived November 15, 2019 from: https://www.klimaschutz.de/projekte/klasse-klima-20)

Nichols, A.L., Maner, J.K. The good-subject effect: Investigating participant demand characteristics. The Journal of general psychology, 135(2):151–166, 2008.

Novak, J., Melenhorst M., Micheel, I., Pasini, C., Fraternali, P. and Rizzoli, A.E.: Integrating behavioural change and gamified incentive modelling for stimulating water saving, Environmental Modelling and Software, Volume 102 (2018) 120-137

Ohnmacht, T., Schaffner, D., Weibel, C., Schad, H.: Rethinking social psychology and intervention design: A model of energy savings and human behavior. Energy Research & Social Science, 26:40–53, 2017.

Pallot, M., Trousse, B., Senach, B., Scapin, D. Living lab research landscape: From user centred design and user experience towards user cocreation. In First European Summer School" Living Labs", 2010.

Parag, Y., Sovacool, B.K. Electricity market design for the prosumer era. Nature energy, 1(4):16032, 2016.

Penny. (n.d.). Retrieved October 10, 2019 from: http://www.penny-project.eu

Pichert, D., Katsikopoulos, K.V. Green defaults: Information presentation and pro-environmental behaviour. Journal of Environmental Psychology, 28(1):63–73, 2008.

Pisello, A.L.; Castaldo, V.L.; Piselli, C.; Fabiani, C.; Cotana, F. How peers' personal attitudes affect indoor microclimate and energy need in an institutional building: Results from a continuous monitoring campaign in summer and winter conditions. Energy and Buildings, 126:485–497, 2016.

Pit, A., Verticale, G., Rottondi, C., Capone, A., Lo Schiavo, L. The role of smart meters in enabling real-time energy services for households: The italian case. Energies, 10(2):199, 2017.

Policy Learning Platform on Low-carbon economy. Improving energy efficiency in buildings. Interreg Europe. 2017.

Prochaska, J.O., Velicer, W.F. The transtheoretical model of health behavior change. American journal of health promotion, 12(1):38–48, 1997.

Rottondi, C., Verticale, G., Krauss, C.: Distributed privacy preserving aggregation of metering data in smart grids. IEEE Journal on Selected Areas in Communications, 31(7):1342–1354, 2013.

Ryan, R.M., Deci, E.L.: Intrinsic and extrinsic motivations: Classic definitions and new directions. Contemporary educational psychology, 25(1):54–67, 2000.

Salleh, M. N. M., Kandar, M. Z., & Sakip, S. R. M. (2016). Benchmarking for energy efficiency on school buildings design: a review. Procedia-Social and Behavioral Sciences, 222:211–218, 2016.

Scheider, S., Raubal, M., Kiefer, P., Sailer, C., Weiser, P. Score design for meaningful gamification. 2015.

Schleich, J., Faure, C., Klobasa, M.: Persistence of the effects of providing feedback alongside smart metering devices on household electricity demand. Energy Policy 107, 225–233 (2017)

Schleich, J. (2009). Barriers to energy efficiency: A comparison across the german commercial and services sector. Ecological Economics, 68(7):2150–2159, 2009.

SMART-UP. (n.d.). Retrieved October 10, 2019 from: https://www.smartup-project.eu/

Sovacool, B. K., Ryan, S. E., Stern, P. C., Janda, K., Rochlin, G., Spreng, D., Wilhite, H. & Lutzenhiser, L. Integrating social science in energy research. Energy Research & Social Science, 6:95–99, 2015.

Tiefenbeck, V. On the magnitude and persistence of the hawthorne effect—evidence from four field studies. In Proceedings of the 4th European Conference on Behaviour and Energy Efficiency, Coimbra, Portugal, pages 8–9, 2016.

Tiefenbeck, V., Wörner, A., Schöb, S., Fleisch, E., Staake, T. Real-time feedback promotes energy conservation in the absence of volunteer selection bias and monetary incentives. Nature Energy, 4(1):35, 2019.

TRIBE. (n.d.). Retrieved October 10, 2019 from: http://tribe-h2020.eu/

Truelove, H. B., Carrico, A. R., Weber, E. U., Raimi, K. T., & Vandenbergh, M. P. Positive and negative spillover of pro-environmental behavior: An integrative review and theoretical framework. Global Environmental Change, 29:127–138, 2014.

Venkatesh, V., Thong, J.Y., Xu, X. Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. MIS quarterly, 36(1):157–178, 2012.

Vine, E., Sullivan, M., Lutzenhiser, L., Blumstein, C., Miller, B. Experimentation and the evaluation of energy efficiency programs. Energy Efficiency, 7(4):627–640, 2014.

Wemyss, D., Castri, R., Cellina, F., De Luca, V., Lobsiger-Kägi, E., Carabias, V. Examining community-level collaborative vs. competitive approaches to enhance household electricity-saving behavior. Energy Efficiency, 11(8):2057–2075, 2018.

Wemyss, D., Cellina, F., Lobsiger-Kägi, E., de Luca, V., Castri, R. Does it last? long-term impacts of an app-based behavior change intervention on household electricity savings in Switzerland. Energy Research & Social Science, 47:16–27, 2019.

Yan, Y., Qian, Y., Sharif, H., Tipper, D. A survey on cyber security for smart grid communications. IEEE Communications Surveys & Tutorials, 14(4):998–1010, 2012.

Yan, Y., Qian, Y., Sharif, H., Tipper, D.: A survey on smart grid communication infrastructures: Motivations, requirements and challenges. IEEE communications surveys & tutorials 15(1), 5–20 (2013)

Yun, G. Y., Kong, H. J., Kim, H., & Kim, J. T. (2012). A field survey of visual comfort and lighting energy consumption in open plan offices. Energy and Buildings, 46:146–151, 2012.

Yun, R. (2014). Persistent workplace plug-load energy savings and awareness through energy dashboards: eco-feedback, control, and automation. In CHI'14 Extended Abstracts on Human Factors in Computing Systems, pages 331–334. ACM, 2014.

Zheng, M., Meinrenken, C.J., Lackner, K.S. Agent-based model for electricity consumption and storage to evaluate economic viability of tariff arbitrage for residential sector demand response. Applied Energy, 126:297–306, 2014.

Zoha, A., Gluhak, A., Imran, M.A., Rajasegarar, S. Nonintrusive load monitoring approaches for disaggregated energy sensing: A survey. Sensors, 12(12):16838–16866, 2012.