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Opportunities and insights for reducing fossil fuel consumption by households and organizations

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Realizing the ambitious commitments of the 2015 Paris Climate Conference (COP21) will require new ways of meeting human needs previously met by burning fossil fuels. Technological developments will be critical, but so will accelerated adoption of promising low-emission technologies and practices. National commitments will be more achievable if interventions take into account key psychological, social, cultural and organizational factors that influence energy choices, along with factors of an infrastructural, technical and economic nature. Broader engagement of social and behavioural science is needed to identify promising opportunities for reducing fossil fuel consumption. Here we discuss opportunities for change in households and organizations, primarily at short and intermediate timescales, and identify opportunities that have been underused in much of energy policy. Based on this survey, we suggest design principles for interventions by governments and other organizations, and identify areas of emphasis for future social science and interdisciplinary research.

In Paris in December 2015, 195 nations made ambitious commitments to reduce their emissions of greenhouse gases. Meeting those commitments will require new ways to meet needs previously satisfied through burning fossil fuels, and will require changes to be implemented rapidly. It will require technological change and the development of new lower-emission and lower-consumption energy sources. But it will also require social change to aid the adoption of these technologies and to implement energy-saving practices.

Many policy approaches for reducing fossil fuel consumption (FFC) emphasize technology development, regulation, financial incentives and information provision. These are useful approaches, but they are likely to fall far short of what is truly achievable if they neglect additional insights from social and behavioural sciences. Such insights help to explain a large 'energy efficiency gap'[1] commonly found between policy expectations based on analyses of technical feasibility and monetary cost, and actually experienced energy use. For example, a retrospective study[2] confirmed a 1990 US forecast that only half of the potential for cost-effective energy efficiency improvements would be realized over the next 20 years. Research is beginning to explain why energy-saving technologies and practices, and renewable energy technologies, are not quickly adopted by those who would benefit, why regulations rarely produce full compliance, and why the targets of financial incentives often fail to take actions that would produce the services they want at the lowest long-run cost to them[3–5].

Analysts continue to debate over the precise magnitude of the energy efficiency gap, its causes and ways to reduce it. It is clear, however, that factors other than straightforward economic rationality can make large differences in the rate at which the gap can be closed. Meeting the Paris commitments will require understanding the practices and decision-making processes of individual, household and organizational energy users, and the entities that influence their behaviour. Such behaviour is shaped in important ways by factors not captured by the simplifying assumptions of 'rational' choice.

Opportunities to reduce FFC exist at multiple social scales and at temporal scales from the momentary to the generational (Table 1). Moreover, change can be initiated not only by governments but also by individuals, households, profit-making organizations, communities, trade associations and other non-governmental actors[6–9]. Generally, changes at the grandest social and temporal scales have the greatest potential for lowering FFC but the weakest base of scientific understanding.

In this Review, we focus on some barriers and opportunities at the levels of households and organizations at timescales up to the intermediate, which roughly correspond to the replacement time for worn-out or obsolete energy-using equipment. We emphasize opportunities that can be realized at any constant state of technology, regulation and price, and we suggest some design principles for interventions. In addition, we consider social processes operating at longer timescales that condition and constrain near-term outcomes. We have not attempted to summarize all the relevant social scientific insights that could be applied to these domains. The boundaries of this Review are hard to define in disciplinary terms because the problem and the relevant research communities are interdisciplinary. It is fair to say, however, that we draw most heavily on research grounded in certain subfields of psychology, sociology, economics and organizational studies.

Reducing fossil fuel consumption by household actions

Households can significantly influence anthropogenic climate change in their roles as direct and indirect users of fossil fuels, as well as through actions as citizens and within organizations[4,10,11]. In the United States and Europe, about one-third of total energy use and carbon emissions results from direct household energy use[12–14]. It has

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Table 1 | Changes to reduce fossil fuel consumption at various social and temporal scales.

Social scales and roles	Temporal scales		
	Short-term (moments to days; for example changing usage of energy-consuming equipment)	**Intermediate (weeks to decades; for example adopting equipment with lower FFC)**	**Long-term (generational, societal transformation)**
Households as energy consumers.	Alter indoor temperature. Turn off lights and appliances not in use. Drive more smoothly. Share transportation. Shift to lower-FFC transport modes.	Replace appliances, HVAC (heating, ventilation and air conditioning) systems and motor vehicles with energy-efficient models. Insulate homes. Adopt photovoltaic systems. Choose small, efficient housing units, with proximity to public transit, shopping and work, when relocating.	Demographic transition to lower birth rates. Multi-generational households.
Household consumption affecting FFC in supply chains.	Purchase low-carbon-footprint foods and services.	Purchase low-carbon-footprint durable products.	Reverse preferences for large, suburban homes, large cars and distant holidays as expression of well-being.
Organizations as energy consumers.	Induce employees to reduce energy use (for instance, in offices, minimize use of task lights, computers, auxiliary heating/cooling devices). Reduce motorized business travel (for example by using video conferencing). Assign staff 'energy champion' responsibilities. Manage production systems in response to real-time price signals.	Make reducing FFC a strategic part of core business operations. Replace lighting and HVAC systems, equipment and motor vehicles with energy-efficient models. When relocating, rent or procure low FFC buildings. Adopt photovoltaic systems. Change work styles to accommodate a broader range of thermal conditions (for example, Japan's Super Cool Biz programme[91]).	Change core business offerings to align with climate challenges (for example BP's short-lived 'beyond petroleum' experiment[89], or Interface Carpet's goal of carbon neutrality[90]).
Organizations as providers of goods and services.	Find lower-footprint supply sources. Inform customers on how to use products and services offered in an energy-efficient way. Reduce FFC in the production chain.	Make reducing FFC a strategic part of core business offerings. Support and train staff in systems thinking and sustainability. Redesign products for lower energy requirements. Elect to manufacture, market and service low-FFC products.	Develop lower-carbon industry-wide standards (for instance, carbon labelling schemes for suppliers).
Large-scale social systems.	Improve crisis responses to power outages and fuel shortages.	Adopt policies to encourage and assist lower-FFC actions in households and organizations. Create institutions and norms for lower-FFC actions in groups of organizations.	Improve public transport system. Design communities to make non-motorized travel easier. Change norms for socially desirable housing, vehicle types, workstyles and work practices.

Actions located in different sections of the table are often affected by quite different factors. Here we emphasize actions by households and organizations at short and intermediate timescales.

been estimated that direct FFC by US households can be reduced by 20% in a decade with conventional technology if the most effective proven non-regulatory interventions are implemented[13]. Similar potential is likely in other high-income countries[15]. This can be accomplished in part by short-term actions such as reducing usage of energy-consuming equipment (for example reducing heating and cooling levels, appliance use or motorized travel), and matching energy demand to available supply of renewable energy carriers[10,13]. In the decadal time frame, the main potential lies in changes in durable household technology, such as adoption of energy-efficient appliances, home heating and cooling systems, and vehicles, as well as improving home weatherproofing (for example insulation). The potential reduction is even greater with adoption of emerging technologies for energy efficiency and use of renewable energy, including solar photovoltaics, wind energy and associated technology such as electric vehicles powered by renewable electricity sources.

Reducing household direct FFC. The most promising targets are actions that have high impact when considering both technical potential (that is, the amount the action reduces carbon emissions) and behavioural plasticity (the number of households that can be induced to act[13]). Greater emission reductions can generally be realized by the adoption of household equipment with lower FFC than by reducing usage — more than three times as much, by one estimate[13]. However, consumers generally incorrectly assume that most savings can be realized by changing usage[10,16].

Behavioural scientists have found that many non-financial influences affect household energy use, including identity and status considerations[10]; perceived social norms[17]; and values, particularly those that reflect concern for other humans and environmental quality[18–20]. Such factors may influence both use and adoption of energy-consuming technologies and renewable energy sources[10]. Values and environmental self-identity can strengthen awareness of energy issues and the environmental consequences of household actions, create feelings of moral obligation to help to reduce energy problems[10,21,22] and provide intrinsic rewards for actions that reduce FFC[23]. Targeting such motivational factors may be a cost-effective approach to reductions of FFC with many households. In fact, several social influence strategies targeting such non-financial factors have been found to be effective in reducing FFC, although effects were mainly observed over short time periods and through altered use of existing household equipment[24]. Strategies that make use of face-to-face interactions, including community approaches, commitment strategies, eliciting implementation intentions and providing social models of desired action, have been particularly effective[24]. Feedback on energy use can also be effective to promote reductions in FFC, especially when provided frequently so that people can link it to their behaviour[25,26]. Interventions are more effective when they are tailored to the target population[25,27].

Research on household adoption of low-FFC equipment has been more limited[28]. Financial incentives have been a favoured policy in this domain. Although they are important for promoting change, they are not a panacea[29], nor are they the only important influence on action. Households' responses to identical incentives for improving home energy efficiency vary by a factor of ten or more, depending on how incentive programmes are implemented[15]. The wide variation in responses to identical financial incentives is associated with non-financial aspects of policy implementation, such as marketing strategies, consumer trust in organizations sponsoring incentive programmes and the level of cognitive effort required for consumers to receive the incentives[30]. Moderate financial incentives may be perceived as not worth the effort and may inhibit further reductions of FFC by inhibiting 'spill-over' to other behaviours[29]. Incentives often underperform expectations when such motivational aspects are neglected[14,30].

Our examination of the available research indicates that the following design principles are embodied in the most effective policies and programmes at the household level: they (1) focus on actions with high potential impact, considering both technical potential and behavioural plasticity; (2) identify and address the key factors, many of them non-financial, inhibiting and promoting the target behaviours in particular populations; (3) attend to programme marketing; (4) provide credible and targeted information at points of decision; (5) make behavioural change and programme participation simple; (6) provide for quality assurance for the programme and the technologies to be adopted; and (7) rigorously evaluate the programme to provide credible estimates of its impact and to decide where improvements can be made[14,28,31]. In our view, principles 2, 5 and 6 are particularly important and frequently overlooked in government-driven energy efficiency programmes. A compatible list of principles, with an additional emphasis on community participation, has been proposed for sustainable energy development in developing countries[32].

The above are general statements. However, significant equity concerns may arise in energy policies[33], and opportunities for reducing FFC differ across locations and among socioeconomic groups[34]. There is active controversy over the extent to which consumers reinvest the economic benefits of energy efficiency in additional energy consumption — what are called rebound effects. Estimated net reductions in FFC vary across populations and measurement techniques, so rebound estimates need to come with caveats. A recent broad literature review of micro- and macro-economic evidence[35] concluded that although estimates of rebound are dependent on methodological choices, the available research does not support claims that energy efficiency gains will be reversed by the rebound effect. Hence, the fact that potential exists for significant household energy savings is not in dispute.

Indirect household influences on FFC. The energy requirements of the production, transportation and disposal of food, goods and services for households amount to about half of total household energy use in Europe[36], but ways to reduce this indirect FFC have received limited attention. Indeed, consumers are often largely unaware of their indirect energy use[37]. Households might be able to reduce this indirect FFC significantly by changing purchasing behaviours, if given credible and readily usable information on the 'carbon footprints' of consumer products[38]. The potential for providing such 'carbon labelling' information, however, is greater with some product classes than others because supply chains are not always readily traceable[39,40], and effective means of providing the information need development.

Reducing fossil fuel consumption by organizational action

Research on organizational factors affecting FFC is relatively scarce[41–44]. Yet, organizations (including industrial and commercial firms, government agencies and other non-profits) account for 60% of energy use worldwide[45] and have considerable potential for reducing FFC[46,47]. The relative scarcity of such research probably reflects disparities in available data[48] and the difficulty of generalizing across a diverse population of organizations that varies greatly in size, function, scope and interest in FFC reduction[42]. Although knowledge across this varied domain is limited, we draw some tentative inferences and point to some promising directions for future work. Following previous work[42,49], this section addresses organizations as both direct consumers of fossil fuels and as facilitators of FFC reductions by others.

Organizations as consumers. Research on organizational energy consumption indicates that there are important opportunities for reducing FFC by adoption of different technologies and operational practices[50]. Many profit-making organizations emphasize increasing revenue and meeting regulatory requirements over reducing costs by consuming less energy[51,52]. Case studies suggest that FFC can be reduced by linking strategic objectives (such as longer-term profitability) to operational value (such as short-term savings)[53,54].

Another opportunity lies in addressing the limited in-house energy expertise that is common even amongst major energy users[55], and particularly in small firms[56,57]. Business alliances have shown considerable promise in helping small businesses operate more sustainably[58]. Initiatives by larger firms are beginning to make a difference[7]. Firms are starting to pursue continuous energy management in a variety of ways, including through a voluntary 'energy management' standard (ISO 50001)[59]. Labelling programmes such as the Carbon Disclosure Project provide third-party verification of actions, enabling investors and customers to provide reputational rewards for low FFC[60].

Split incentives — where one party bears the costs of investing in lower FFC but another reaps the rewards — are pervasive both within and across organizations[51], affecting up to 90% of the energy used in many major markets[61]. For example, design and purchase decisions by building developers and owners affect tenants' energy bills. In several countries, local governments have begun mandating that commercial building owners disclose their energy bills, and this is motivating building owners to invest in energy efficiency by making building energy performance more visible to tenants, landlords and investors[48,62–64]. New 'green' leasing agreements in Australia, the United Kingdom and other countries are enabling landlords and tenants to meet environmental targets cooperatively by sharing performance goals, energy data and upgrade costs[65,66].

Empowering building operators can result in 5–30% reductions in FFC[67]. Further opportunities exist for reducing FFC by engaging individual employees to change work practices.

Information technologies and social media offer new opportunities to expand energy information and engage employees[68,69]. Promising opportunities exist to motivate work groups at different levels within and across organizations[43,70,71].

On the basis of our reading of the literature, we have identified the following general conclusions and design principles for interventions to reduce FFC by organizations: (1) focus interventions on the key influences that guide the actions of specific target organizations; (2) consider influences that come from both internal organizational factors (such as size, business strategy and staffing) and inter-organizational relationships (such as market supply-chain relationships); and (3) use regulatory requirements and other opportunities to make energy performance information more public and thus enable reduction of split incentives.

Organizations as facilitators for reducing FFC. Additional opportunities exist because organizations and organizational networks can influence FFC by households and other organizations by designing, manufacturing and marketing clean energy supply alternatives and high-efficiency buildings, vehicles, equipment and devices[72]. Research is exploring how organizations serve as 'middle actors' in energy systems by enabling FFC reduction upstream (for example in policy), downstream (for example by clients) and sideways (for example by other middle actors)[8,9].

Organizational network analysis shows how the provision of goods and services and associated FFC involve relationships among organizations. A building, for example, forms part of a value chain[73] that connects design firms, project developers, financiers, owner/investors, real-estate service providers, contractors, building operators and occupants. Research on insulation, housing and commercial buildings shows that networks of professional and industrial organizations influence the extent to which low-FFC strategies manifest in the building design and construction process[8,74–77]. Similarly, lighting and appliance manufacturers and other organizations constrain the choices of ultimate energy users[49,72]. These relationships suggest opportunities for government action to develop, facilitate and require the adoption of high-efficiency equipment[78], and also highlight the possibilities for key organizations in value chains to influence entire chains[49,70].

Outlook

Behavioural and social insights going beyond simple assumptions of rational economic decision-making make possible significant reductions in FFC by households and organizations at short to intermediate temporal scales (see Table 1)[7,13]. In the household sector, reductions of at least 20% are reasonably achievable with well-established technologies in a decade in some high-income countries[13,15]; even greater reductions are possible through adoption of renewable energy sources and related technologies. The potential for reducing FFC by organizations and through changes in value chains and provider networks may be even greater, but, because of a limited research base and the great variety among organizations, has not been quantified.

Some significant barriers and opportunities for reducing FFC apply both to households and many organizations, so deserve special attention. Some involve 'energy invisibility'[3], in which the high-impact activities and the most promising opportunities for reducing FFC, including those involving embodied energy, are not immediately evident to energy users at both levels. If consumers must identify these for themselves, the required effort is often prohibitive. Both governmental and private actors can help entire classes of consumers find high-payoff opportunities, for example with carbon labelling and energy auditing efforts. They can also help in implementing the design principles of quality assurance and rigorous evaluation. However, research will be needed to: (1) identify actions with high practical potential (taking into account both technical potential and behavioural plasticity) for particular types of decision-makers; (2) identify the factors that can assist those actions; (3) develop and validate indicators of FFC, including that embodied in products and services, to better inform choices; and (4) identify effective synergies of efforts by multiple actors. This research will require collaboration among scientists from multiple disciplines within and beyond social science and integration of their insights. Social scientists in particular will need to turn more attention from testing existing theories to understanding the choices offering the greatest potential FFC reductions for particular subgroups of households and organizations, based on their particular psychological, social, cultural and technical characteristics and environments.

Realizing the ambitious Paris commitments will also require change at larger social and longer temporal scales (see Table 1). Although the knowledge base here is limited, some general guidance is available[5,7,41,70,79]. On longer timescales, the greatest opportunities are likely to lie in technological innovations, social movements, and infrastructural and cultural changes that drive actions on shorter timescales and affect multiple social scales. To realize long-term global goals, it will be crucial to engage the full range of the social and economic sciences along with natural sciences, engineering and planning, and to integrate insights about households and organizations with insights about the social, cultural, political and economic processes that shape human choices and behaviour at all scales.

Promising work, primarily in Europe, on 'social practices'[80] has been studying how the habits and choices of individuals and groups are strongly shaped by cultural beliefs and large-scale social actors that help to create the needs that are now met by FFC. Key insights from this work concern the nuanced interplay of actors across time and scales of social organization and indicate that achieving change in large-scale systems of production and consumption can benefit from lessons drawn from changes in the past. Applications of insights from recent European 'socio-technical transitions'[81] studies may help shape future transitions to much lower FFC levels. Also, macro-scale sociological and anthropological work on energy use and diverse consumer lifestyles[82] and workstyles[70], the influences of cultural and demographic changes on FFC over time[83], the social and equity impacts of energy policies[84], and experience with interventions for energy efficiency through market transformation involving supply chains within the United States[85] can all be applied to accelerating longer-term social and technological changes to reduce FFC. We have not examined the broad array of macro-scale theory and research in detail because of the shorter-term focus of this paper. Going forward, it will be important to draw widely on relevant work across scales and social science disciplines, as well as fostering conversations between researchers and policymakers, to navigate the tension between the desire for general solutions and the specifics of social context[86].

Careful and rigorous evaluation of interventions is important for understanding, quantifying and achieving their full potential[87], and will enhance fundamental understanding[24] and improve allocation of resources, but action need not be postponed. Strategies, such as community-based approaches, exist for identifying realistic interventions for reducing FFC even in the absence of precise evidence from evaluations[88]. Governments, communities and organizations must be willing to innovate further and use experimental design to find out what does and does not work.

We note that most research so far has been conducted in industrialized countries. Different opportunities and barriers may dominate in developing countries, where research is needed to understand opportunities to advance well-being without following the fossil-fuel-intensive development paths worn by current high-income countries. Finding alternative development paths will require the integration of technological, economic, social and cultural sciences.

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Competing interests
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