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Energy Policy 34 (2006) 3065–3077

ENERGY POLICY

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Evaluating the applicability of integrated domestic energy consumption frameworks in the UK

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Available online 14 July 2005

Abstract

Domestic energy consumption (DEC) has been traditionally understood using disciplinary perspectives, focusing on specific components of the energy consumption system such as technologies or costs. However, early attempts to encourage energy conservation demonstrated that these frameworks often miss important contextual factors such as cultural values and behavioural interactions with technologies. This evidence, combined with the present need for energy policies that can address environmental, social, and economic concerns, suggests that a broader perspective is needed. Integrated frameworks of DEC were first proposed over 20 years ago but very little has been said about the ideas proposed in these papers, whether it be critiquing their form or assessing their impact on theory and practice. This paper attempts to fill this gap by examining the influence of integrated frameworks in academic literature and in UK energy policy. It is argued that a common language could stimulate renewed interest in the integrated perspective and thereby help policy makers meet these diverse goals. To this end, a flexible agent-based framework is proposed to stimulate debate and clarify the role of an integrated approach to domestic energy policy.

Keywords: Domestic energy consumption; Integrated framework; Agent-based

1. Introduction

The oil crises of the 1970s mark a watershed for the energy policy of industrialised nations, as decision makers began serious assessments of the domestic sector and its role in achieving security of supply. The needs of energy policy have expanded since then to include environmental sustainability and market liberalisation (Helm, 2002b), ensuring that the domestic sector remains a central concern. For example, domestic electricity consumption in the UK has risen 3% per annum since 1970 driven largely by the proliferation of domestic appliances and smaller household units (i.e. more households) (Boardman et al., 1995). This continued growth places pressure on policy makers to meet this demand within a modern liberalised market while at the same time ensuring social equity in energy services, reducing dependence on foreign energy sources, and reducing the environment impacts of energy use (especially climate change) (DTI, 2003b). This last point is especially relevant as the recent enactment of the Kyoto Protocol commits 141 nations to reduced greenhouse gas emissions, reductions which may have a significant impact on the domestic sector.

Despite these diverse goals, policy measures in the domestic sector frequently have a narrow scope, concentrating on particular technical or economic measures. A brief example is the UK's Clear Skies and Major Photovoltaic Demonstration grant programmes which provide technology-specific grants for renewable energy and energy efficiency in households. While these programmes reduce the greenhouse gas emissions of participating households, the impact for the whole of the domestic sector seems limited, given limited rates of adoption and uncertain institutional support, such as export metering and tariff arrangements for renewable micro-generation. Therefore one must question if these

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doi:10.1016/j.enpol.2005.06.004

small and specific policy measures will be sufficient to the address the challenge of growing energy use in the domestic sector and its role in climate change.

Within academia, think-tanks, and government there are a diverse range of frameworks to conceptualise domestic energy consumption (DEC) and these philosophies in turn shape the creation of analysis tools, policies, and even the public perception of energy issues. Traditionally, a disciplinary approach has been dominant with economists and engineers guiding most domestic energy policy. However there are limitations to such approaches that become more apparent when confronted with the multifaceted problems facing the domestic energy sector today. In response, an alternative to the disciplinary perspective has been proposed by a small body of literature. These "integrated" frameworks[1] attempt to rectify the short-comings of narrow conceptualisations of DEC, by outlining a complex web of interactions between technology, economics, society, culture, and other factors. However although they were first introduced nearly 20 years ago, very little has been written about the models themselves, questioning their scope and exploring their impact on policy and theory.

Therefore the aim of this paper is to review existing integrated models of DEC, investigate whether or not they are being adopted, and evaluate their current and potential role in energy policy. Though this topic is relevant to many western nations, the UK has been chosen as a reference case for part of the analysis and discussion. In Section 2, the integrated frameworks of DEC will be reviewed and contrasted with disciplinary approaches. A typology and definition for such models will also be proposed. In Section 3, bibliographic data is examined to see how integrated models have evolved in the academic literature. A recent UK energy policy document is also assessed to explore the model in practice. In Section 4, an agent-based integrated framework is proposed to address some of the challenges facing this approach and to highlight areas for future work.

2. The frameworks of domestic energy consumption

DEC refers to the energy consumption of a household unit within their dwelling and in the UK, this sector accounts for 28% of total delivered energy (DTI, 2003a). For the purpose of national and international assessments, DEC specifically means the energy used for activities such as lighting, space heating, water heating, appliance use (consumer electronics, white goods and so on) and cooking (IEA, 1997). For each of these applications, the amount of energy used and its subsequent impact is a function of not only the equipment employed and duration of use, but also the associated fuels, economic incentives, and even social and psychological perceptions of energy and energy services. Correspondingly, the literature on DEC largely consists of disciplinary models focused on a particular part of this demand cycle.

2.1. Disciplinary frameworks

DEC has been studied primarily by four disciplines—engineering, economics, psychology, and sociology or anthropology—with each subject bringing its own techniques, frameworks, and biases to bear on the problem. For example, *engineering* studies explore the technologies of the domestic sector and determine consumption by physical laws (e.g. heat transfer). Examples of this approach can been seen in heating (Anderson and Building Research Establishment, 1985), lighting (Stokes et al., 2004) and appliances (Hart and de Dear, 2004). While many policy instruments concentrate on this technical level (Shorrock and Dunster, 1997), the human behaviours which drive energy demand are often assumed from past records or estimated from statistical methods (e.g. Capasso et al., 1994). These assumptions may be acceptable for aggregate analyses but at smaller scales, "the individual consumer—and ... the random components of demand become very important" (Stokes et al., 2002, p. 4). Furthermore, behavioural responses to technical improvements are beyond the scope of the engineering model; for example a technical study of home heating in Ireland was unable to determine whether improved insulation would result in less fuel consumption (that is, maintaining the pre-insulation temperature) or a higher standard of living (that is, increasing household temperature) (Clinch et al., 2001; see Milne and Boardman (2000) for more discussion of this issue).

The *economic* approach also offers strong numerical analysis but as a social science, it introduces elements of human behaviour. Typically used to understand the impact of energy taxes, price effects and income levels on DEC (Baker, 1991; Greening et al., 1995; Ruffell, 1977), this conceptualisation views the household as a utility-maximising unit of production and consumption (Ironmonger et al., 1995). However empirical evidence has shown that households frequently fail to obey these assumptions of rational behaviour (Brechling and Smith, 1992; Cogoy, 1995; Fernandez, 2001; Kooreman, 1996). Whether this is caused by a lack of information (Kempton and Layne, 1994), the framing of decisions (Tversky and Kahneman, 1986) or the complex dynamics of the household unit (Johnson, 1971; Kooreman and Wunderink, 1997; Ulph, 1988; Wheelock and

[1] In this paper, the words "framework" and "model" are used interchangeably to avoid repetition but both refer to a conceptualisation of domestic energy consumption, and not necessarily a model in the sense of computer simulation.

Oughton, 1994), evidence suggests that the economic conceptualisation of human behaviour and energy use is incomplete.

Together the engineering and economic approaches make up the physical–technical–economic model (PTEM) of DEC, which enjoys a significant influence in the creation of energy policy (Lutzenhiser and Hackett, 1993). However it has long been argued that social scientists can make an important contribution to our understanding of DEC (Schnaiberg, 1975; Winnett and Ester, 1983); specifically to address the PTEM's "serious blind spots in the area of human behaviour" (Stern, 1992: p. 1224). To this end, *psychology* has contributed by exploring the internal motivations for the energy consumption behaviour of individuals. In the case of energy conservation, some of these drivers include 'intrinsic' satisfaction (DeYoung, 1996; Seligman et al., 1979), guilt and moral responsibility for energy use (Kaiser and Shimoda 1999), and commitment to conservation (Heberlein and Warriner, 1983; Katzev and Johnson, 1983). Others have used psychological decision models, such as the Theory of Planned Behaviour (Ajzen, 1991), and found support for their use in DEC applications (Banks, 1998; Stutzman and Green, 1982). However psychological studies, which rely largely on personal constructs such as attitudes and values, have less to say about the social and cultural contexts of energy use behaviour (Guagnano, et al. 1995; Stern et al., 1995).

While early attempts to examine energy and society lacked a proper theoretical framework (Rosa and Machlis, 1988), *sociological and anthropological* studies have demonstrated the importance of social context in understanding DEC; for example, in energy use and housework (Cowen, 1983), the evolution of domestic appliances (Hardyment, 1988), and our changing perceptions of comfort and cleanliness (Shove, 2003). This has led to concepts such as lifestyle analysis (e.g. Wolvén, 1991), the cultural inertia of technological systems (Lutzenhiser and Hackett, 1993), and "obligatory" or minimal culturally accepted levels of consumption (Hackett and Lutzenhiser, 1991; Wilhite and Lutzenhiser, 1999). However these concepts have been communicated primarily in qualitative terms, often in reference to individual households, and until quantitative sector-wide translations are made, it seems unlikely that these ideas will have as much influence with policy makers as the PTEM.

2.2. Integrated frameworks

Disciplinary models make significant contributions to our understanding of DEC but within narrow areas of speciality. These limitations were first recognised over twenty years ago when studies of energy conservation (triggered by the oil crises of the 1970s) revealed that the anticipated energy savings of conservation programmes were not occurring, due to a poor understanding of the complex interactions between technology, policy, and the consumer. The overall conclusion—that DEC "can no longer be viewed as a purely technical or economic problem but as a people problem as well" (Yates and Aronson, 1983, p. 435)—remains true today, especially when the problem of climate change demands significant alterations in energy consumption. Thus an integrated approach that can apply specialist expertise while recognising the issue's larger context is necessary for those trying to address the multifaceted challenges of modern energy policy. Academic research also benefits from integrated models, as the popularity of interdisciplinary projects necessitates an inclusive approach. I propose to define an integrated framework as:

> A conceptualization of domestic energy consumption that acknowledges the expertise of disciplinary approaches but seeks to situate this knowledge within the broader context of energy consumption including social and behavioural factors.

Five integrated frameworks of DEC have been identified as notable examples of the field. They were chosen following a review of DEC studies which revealed that theoretical conceptualisations of DEC remain largely disciplinary. In contrast, the approach of these integrated studies stood out as unique and a further improvement upon the contributions that hybrid disciplines (i.e. partially integrated, such as economic psychology) have made to our understanding of DEC. The studies are:

- The behavioural model (van Raaij and Verhallen, 1983)
- The political economy model (Dholakia et al., 1983)
- The cultural model (Lutzenhiser, 1992)
- The systems approach (Hitchcock, 1993)
- The global consumption model (Wilk, 2002)

It is beyond the scope of this paper to provide effective summaries of each article but three key observations can be made. First, each article cites the limitations of disciplinary approaches as a justification for an integrated framework. In the case of van Raaij and Verhallen (1983), this inspiration came from the observed failure of households to be more energy-conscious and they noted six barriers covering a range of technical, economic, and social factors.

Secondly the variety of models proposed is impressive, due to the diverse backgrounds of each author. This demonstrates that no single integrated model has emerged as the accepted form but also, these different concepts of integration provide a unique opportunity to judge, for example, how marketing experts such as Dholakia et al., view DEC compared to an engineer like

Table 1
A typology of integrated frameworks

Study	Axes of differentiation		
	Application	Form	Scale
Dholakia et al.(1983)	Theory	Structure	Broad
Van Raaij and Verhallen (1983)	Hybrid	Structure	Hybrid
Lutzenhiser (1992)	Practice	Hybrid	Narrow
Hitchcock (1993)	Practice	Structure	Narrow
Wilk (2002)	Theory	Process	Hybrid

Hitchcock. As a result, a typology of the models can be created along three axes of differentiation as seen in Table 1: application, form, and scale of analysis.

2.2.1. Application

DEC frameworks can lend themselves toward theoretical (i.e. stimulating debate) or practical (i.e. guiding policy) applications. Among the disciplinary approaches, economics and engineering clearly favour practical applications: "the subsidy should be $\$x$/kWh" or "improving insulation will reduce energy demand by y%", whereas the lessons of anthropology are more difficult: how does one translate "cultural values" into a specific course of action? The application attribute in turn determines the audience that can seek out and use the findings, as suggested by policy makers favouring the PTEM. Integrated frameworks should ideally address both theory and practice but the studies reviewed often lean towards one extreme or the other. As an example, Hitchcock's systems approach focuses on practice by providing recommendations for the translation of quantitative values from a behavioural model to a technical consumption model.

2.2.2. Form

The second consideration is the form of an integrated framework and the two proposed extremes are structure and process. A structure framework attempts to provide a template within which the work of others can be placed and therefore focuses mainly on the arrangement and links between individual elements (e.g. van Raaij and Verhallen, 1983). In contrast, a process framework concentrates primarily on the linking mechanisms, which bind the entire DEC process. This is the case with Wilk's "*multigenic* theory, which accepts that there are multiple determinants of consumption, operation at different conceptual and analytical levels" (2002, p. 9, author's italics). It may appear that a framework's form and its application are very similar, as a process model such as Wilk's suggests a theoretical application. However, he demonstrates the difference in these two attributes by showing how policy recommendations can be derived directly from the implications of the model's process analysis, using the case of kerosene consumption in South Africa. A successful integrated framework should balance these two extremes, accounting for all elements of the DEC system but also providing an explanation for how they work together.

2.2.3. Scale

Finally there is a question of scale, from narrow to broad. As noted above, disciplinary models frequently have a narrow scale; that is, they investigate one part of the DEC process in great detail—be it technology, price signals, or psychological processes of an individual. Integrated frameworks have a larger remit but the exact scope can vary. Consider information feedback, which has been shown to have great potential for conservation (see Darby, 2000 for a review of feedback studies). The form of the feedback determines how it will influence DEC; for example, an electronic meter that shows consumption in instantaneous kilowatts might emphasise turning off equipment at a particular time, a monthly bill would stress the financial aspects of energy consumption, and a personal carbon quota might emphasise personal responsibility for one's energy consumption. An integrated framework with a large scale of analysis will be able to incorporate more feedback mechanisms (e.g. van Raaij and Verhallen, 1983) than one which only includes a few components (e.g. Hitchcock, 1993). At the same time, it must also be able to explore the details of particular feedback mechanisms, again demonstrating a need to balance the two extremes.

The final, and perhaps most surprising, observation is that the integrated frameworks presented here have failed to refer to one another, with the notable exception of Hitchcock who refers to all of the integrated models that precede his study. In Lutzenhiser's 1992 study, he correctly laments that little effort has been spent bringing together social and technical models of DEC although van Raaij and Verhallen's notable contribution is not reviewed. While this may be an artefact of Lutzenhiser's representative sample methodology, compounded by differences in search technology and limited journal access prior to the internet, the conclusion is that there has been little debate about the merits of various models and what form a unified integrated framework might take. These works are often cited not as a unified body of literature but individually, as justification for specific disciplinary work (e.g. Greening, 2004; Wood and Newborough, 2003). Examining the impact of the integrated framework as a concept and its contribution to energy policy is therefore long overdue and timely, given the ongoing importance of interdisciplinary

research and the complexities of modern energy policy (Lutzenhiser and Shove, 1999; Stern, 1993).

3. Examining the evidence

Assessing the impact of integrated frameworks is difficult. Tracking a particular school of thought largely relies upon published literature to indicate any trends, even though ideas can spread in many other ways such as social networks or the priorities of funding bodies. Furthermore, publications that are not indexed (e.g. reports from private research institutions) are very difficult to track through the literature. This point is particularly relevant to this study, as the Environmental Change Institute has undertaken several DEC projects using an integrated approach, though the findings were published primarily in non-indexed reports (e.g. Boardman et al., 1995; Palmer and Boardman, 1998; Winward et al., 1998). Acknowledging these limitations, the review presented below is intended as an estimate of influence in both theory and practice.

To explore the academic influence of the integrated DEC framework, a multi-disciplinary citation index (ISI, 2004) was searched for domestic energy articles from 1981 to July 2004. This methodology was inspired by a similar review, conducted for Lutzenhiser's cultural model paper (1992), and it involves sorting articles into category by discipline. Using the search query ''(domestic OR household) AND (energy OR electricity) AND (consumption OR demand)'', a total of 852 studies were identified and grouped by Lutzenhiser's original categories: engineering, economics, psychology, sociology and anthropology, consumer conservation behaviour and conservation program evaluations (this was expanded to include other forms of direct intervention such as feedback studies), policy analysis and demand forecasting, and international studies. An "other" category was added as well to capture work from areas unrelated to DEC but which matched the search criteria (e.g. biological systems and nutrition). Many studies could have been categorised in different ways but the journal titles, keywords, and abstracts were used to sort the articles into their most relevant field. These studies were then divided into larger disciplinary (engineering, economics, psychology, and sociology/anthropology) or interdisciplinary (consumer behaviour, policy analysis, and international studies) groups. The sorting procedure is inevitably subjective and so further bias was minimised by performing all the sorting in one day, by the author only. After removing 340 "other" studies, the remaining 512 articles were sorted by category and group as presented in Table 2; values from the 1992 Lutzenhiser study are presented for comparison.

A χ^2 test reveals a significant difference between the 1992 and 2004 category data ($\chi^2 = 336$, $df = 6$, $p < 0.001$), confirming that the 2004 results show proportionally more international and engineering studies and fewer contributions from sociology, anthropology, psychology, and consumer behaviour. There are two possible explanations. First, the subjective nature of the categorisation exercise means that sorting criteria may have been applied unequally between the two studies. However there is no significant difference between the results of the 1992 and 2004 surveys when using the larger disciplinary or interdisciplinary groups ($\chi^2 = 387$, $df = 1$, $p = 0.534$), providing some assurance that the methodology is consistent. An alternative explanation is that there has been a genuine shift in the literature during the elapsed time between the two surveys. These general trends will now be investigated further.

3.1. Trends in DEC literature

The main goal of the analysis was to explore the mix of disciplinary and interdisciplinary studies over time and thereby determine whether or not the academic community was focusing on specific parts of the DEC question or broader issues. As outlined above, disciplinary studies include engineering, economics,

Table 2
Studies of domestic energy consumption

Group	Category	2004 results (covering 1981–2004)		1992 results (from Lutzenhiser, covering 1975–1987)	
		Count	%	Count	%
Disciplinary	Engineering	133	26	47	12
	Economics	83	16	35	9
	Psychology	11	2	30	8
	Sociology/Anthropology	29	6	73	19
Interdisciplinary	Consumer behaviour	27	5	88	23
	Policy analysis	74	14	59	15
	International	155	30	56	14
Total		512	100	388	100

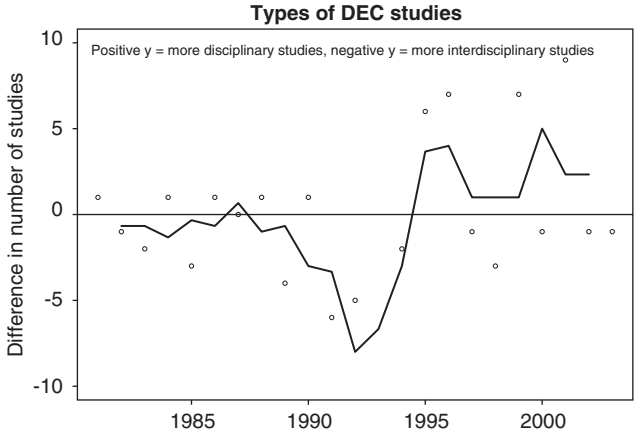

Fig. 1. Difference in the types of all DEC research.

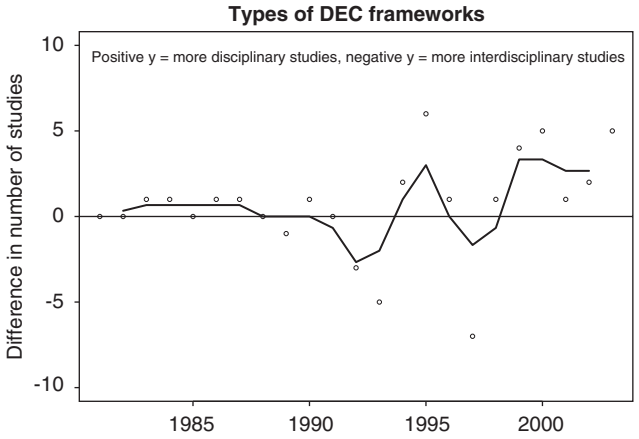

Fig. 2. Difference in the types of theoretical DEC research.

psychology, and sociology/anthropology, whereas interdisciplinary studies cover the consumer behaviour, policy analysis, and international studies categories. Fig. 1 shows the difference between the number of studies in each group with a 3-year moving average. The negative area in the early 1990s demonstrates a preference for interdisciplinary studies; this may be because the early integrated framework articles of the 1980s have percolated through and inspired a series of interdisciplinary studies. However in recent years disciplinary studies have been more common, perhaps because evaluating the mechanisms of the Kyoto Protocol suggests technical or economic policy assessments (e.g. Helm, 2002a). Examining the entire difference time-series however, there is no significant difference between the two approaches (Shapiro–Wilk normality test, $W = 0.9283$, $p = 0.101$; T-test; $t = -0.396$, df $= 22$, $p = 0.696$).

These results were then filtered to isolate DEC studies that explicitly referred to a particular theoretical approach. This was achieved by identifying articles from the original DEC search results that mention the word "model", "framework", "perspective", "method", "theory" or "approach", their plurals and other conjugations (e.g. modelling, models, etc.) in their titles. The synonym "system" was omitted as it has strong engineering associations that might bias the results and six keywords were deemed to be a sufficient sample. The resulting studies were again divided into disciplinary and interdisciplinary groups as above and the two approaches compared as shown in Fig. 2 (with a 3-year moving average). This also shows that in recent years, the disciplinary approach has become more common but there is no significant difference between the different theoretical approaches over the entire time-series (Shapiro–Wilk normality test, $W = 0.898$, $p = 0.0231$; Wilcoxon test: $V = 121$; $p = 0.123$).

Finally, two general trends in the citation index were investigated to provide a context for the analysis: the ratio of energy studies to all studies and the ratio of DEC studies to all energy studies. First the citation index was searched for all articles matching the term "energy"; the search engine automatically returned the total number of indexed articles as well. A time-series was plotted, revealing a notable jump for energy literature in 1991, likely as a new group of energy-related journals was added to the citation index. Since 1991, energy studies have accounted for an average of 4.1% of all indexed research ($\sigma = 0.27\%$) and this fraction is steadily increasing (post-1991 Pearson correlation, $c = 0.93$, $p < 0.001$). Next the ratio of DEC articles to all energy articles was calculated. It was found that DEC studies account for an average of 0.063% of all energy literature ($\sigma = 0.024\%$) and there is a weakly correlated increasing trend ($c = 0.663$, $p < 0.001$). However, no significant conclusions can be drawn from these results because searching for "energy" articles also returned a large number of articles from physics, chemistry, biology, and other unrelated disciplines. Attempts to resolve this dilemma were made using other search queries but satisfactory results could not be obtained.

These results therefore suggest that while interdisciplinary studies have been equally matched with disciplinary studies overall in the past twenty years, recent years have seen a growth in disciplinary studies. This finding was echoed by the proxy measures of academic practice (all studies, Fig. 1) and theory (framework studies, Fig. 2) presented above. While this analysis identifies a general disciplinary trend in recent years, it does not show the influence of individual integrated frameworks and therefore a closer look is required.

3.2. The influence of specific integrated frameworks

Given the difficulty of determining the exact theoretical background of several hundred papers, the five studies identified above (Luztenhiser, van Raaij and

Verhallen, Hitchcock, Dholakia, et al., and Wilk) were examined in more depth, exploring how these examples of an integrated approach to DEC have spread throughout the literature. First the ISI Web of Science citation index was used to calculate an influence score for each article, computed with a time-weighted average to account for differences between when each article was published. The articles and their influence scores are as follows, with a larger score indicative of a greater influence in the literature: Lutzenhiser 5.5, van Raaij and Verhallen 3.3, Dholakia 2.8, Wilk 1.0, and Hitchcock 0.73. Fig. 3 shows these citations with the publication of each model represented by a black circle and subsequent citations indicated by open circles; the larger the circle, the more citations in that year.

The two most significant articles are Luztenhiser and van Raaij and Verhallen. From the typology of models (Table 1), it is clear that these studies are quite different and this is reflected in the types of articles that cite each paper. For example, Lutzenhiser's article is cited primarily by energy literature, especially energy economists (e.g. Greening et al., 2001; Poyer et al., 1997); in contrast, van Raaij and Verhallen's work has had a greater influence on psychology, consumer behaviour and marketing literature (e.g. Linneweber, 1995; van Houwelingen and van Raaij, 1989). In the case of Lutzenhiser, whose study demonstrates how lifestyles can be used as a tool for analysis, this is a positive development resulting in economists diversifying their work with sociological elements. However, van Raaij and Verhallen's framework has stayed within the marketing and consumer psychology literature and has not crossed over to other disciplines as effectively. This is shame because marketers have experience applying a more integrated approach to the sale of goods and services; as Lutzenhiser notes "the whole point of marketing, after all, is to induce purchase through

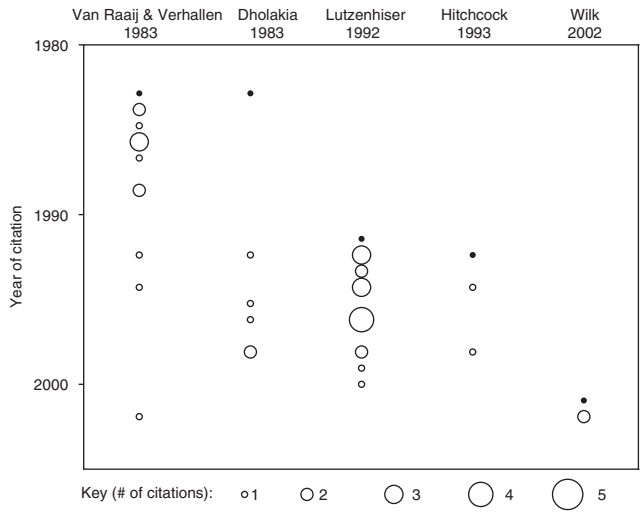

Fig. 3. Tracking the influence of specific integrated frameworks.

appeals to *non-economic* motives." (1992, p. 52, author's italics). In other words, this practical knowledge of the diverse motives of behaviour is exactly what is required to understand what does and does not work with DEC and therefore it is disappointing that this particular study has not reached a wider audience.

The lack of citation amongst integrated models is also noted, suggesting that there has been little debate in the literature about the ideas proposed in these papers. The exception to this is Hitchcock's paper, which cites the models of Lutzenhiser, Dholakia et al., and Van Raaij and Verhallen. However, the author interprets these papers separately and not as variations on a single theme, as this paper suggests.

3.3. Integrated frameworks in policy

Much of this discussion has alluded to the policy environment, with the implication that an integrated model of DEC would facilitate policies that successfully address the various causes of DEC, from individual behaviour to institutional capacity (Hinchliffe, 1995; Varone and Aebischer, 2001; Weber, 1997). Failure to account for these many factors can lead to unexpected results, as in the case of UK wind energy where the government's subsidies have not yet been able to deliver the desired targets because of strong cultural opposition to the projects (Strachan and Lal, 2004). However, there are some successful examples in DEC, such as market transformation and labelling policies on appliances and lighting (Palmer and Boardman, 1998; Winward et al., 1998). Therefore it is worth assessing how energy policy is currently being formulated to see what level of integration has been employed, in particular regarding the domestic sector. Although the UK will be used as an example case, the concerns and policies discussed here are similarly applicable to other western nations trying to deal with growing energy demand, environmental concerns, and security of supply, among other issues.

The UK's recent energy white paper, *Our Energy Future: creating a low carbon economy* (DTI, 2003b), was chosen as a relevant policy example. Its preamble identifies four goals—to get on the path to a 60% reduction in carbon-dioxide emissions by 2050, to maintain a reliable energy supply, to promote competitive markets and economic growth, to ensure every home is adequately and affordably heated. Of particular note, the white paper's emphasis of environmental and equity issues imply a broader—more integrated—approach to UK energy policy. For example, if significant levels of renewables are to be introduced to the domestic sector, the concurrent liberalisation of metering services, technical assessments of distributed generation, and the promotion of domestic renewable energy technologies must work together. Likewise, the

promotion of energy efficiency can deliver results for the environment, fuel poverty, and security of supply.

The white paper's scenario for UK energy in 2020 emphasises disciplinary policies such as technical improvements (e.g. low-energy homes) and economic policies (e.g. carbon pricing), and does not directly discuss the social and cultural changes which could act as barriers or catalysts for these reforms, although funding has been provided for the UK Energy Research Centre whose mandate includes social studies. Given early evidence that these policies may not succeed (BBC News, 2004; Helm, 2002a), it seems that the goal of a 60% reduction in CO_2 emissions by 2050 is unattainable without broadening the scope of proposed policies. To achieve these steep emission reductions, an integrated framework could highlight the social and cultural changes that must accompany technological and economic measures. For example, encouraging household adoption of micro-generating renewables is a positive development but ongoing research at the ECI suggests that the impact these technologies have on consumption, by increasing awareness of energy use, may be limited by poorly coordinated metering and tariff arrangements. Therefore, the conclusion one draws is that although the UK government appreciates the links between different parts of energy policy, it continues to rely largely on economic incentives or technological fixes instead of tackling the difficult social, institutional and cultural implications of desired policy goals.

Overall, these analyses have shown that integrated frameworks of DEC have had a moderate impact. As represented by the five sample studies, the integrated approach has a presence in academic literature, though this is currently limited to revising the shape of disciplinary studies and has yet to stimulate significant cross-disciplinary research, notably from the marketing sector to other disciplines. Disappointingly there has been almost no discussion of the integrated framework as a concept, what form it might take, and how it might direct more focused research and policy. Given the policy challenges currently faced by the UK government, perhaps now is the time to learn from these early works and move forward with a unified integrated framework.

4. Building a unified integrated framework

Before outlining the proposed framework, two guiding principles are established. First as Stern (1993) notes, advancing interdisciplinary or integrated research can be difficult as the disciplinary approach is ingrained in funding structures, research councils, and as some would argue in the UK, research assessment exercises (RAE, 2000). Therefore the framework outlined here aims to work with existing disciplinary structures by introducing the integrated approach in a compatible manner.

Secondly, the typology of integrated models indicates that a successful integrated approach should be as inclusive and flexible as possible, balancing the extremes shown in Table 1. First it should be useful in both theoretical and practical applications, so that academic debate might translate quickly and transparently to policy solutions. Second its form needs to provide a framework for aligning disciplinary studies, but it should also inform the processes by which these elements are linked. Finally, it should be inclusive enough to situate all aspects of DEC (broad scale) and flexible enough to explore the details of a specific issue (small scale).

With these principles in mind, I propose an agent-based integrated framework. At this early stage, and in the context of this paper, it is not feasible to describe such a framework completely. Therefore the discussion that follows is a sketch, in which I hope to establish that (a) an agent-based vocabulary is a practical and accessible way of integrating the various aspects of DEC and that (b) existing research in actor-network theory (ANT) and agent-based modelling (ABM) supports this vocabulary and can provide the necessary tools to advance this approach.

4.1. Theoretical considerations

As discussed, research on DEC places significant and growing emphasis on specific elements of the consumption system, such as technologies or economic incentives. This detailed focus is important when exploring the finer points of a topic but it can be difficult to situate these findings within the overall DEC picture, especially for non-experts where disciplinary jargon can be an obstacle to understanding. Fortunately, these subsystems can be represented as tangible actors or agents.

As a somewhat naïve example, consider the issue of market transformation in domestic appliances. A researcher trying to encourage the uptake of more efficient appliances might examine the various policy options that a government could follow, perhaps debating the finer points of command-and-control versus voluntary agreements. This detailed analysis may be beneficial and insightful but to non-experts, it is essentially a discussion of the links between government and manufacturers. At this broader level, one can then see how other agents are relevant to this debate: households may provide a pulling demand for efficient appliances, the technologies themselves may not yet be available and even the environment must be considered as it bears some of the costs and benefits of such a policy. The issue of market transformation can therefore be interpreted as a network of different actors whose interactions determine the success of the entire enterprise (e.g. Blumstein et al., 2000). Clearly research must

still focus on particular elements of this network but the agent-based vocabulary makes it easier to identify the links within the network, especially for non-experts.

The theoretical grounding for this proposed framework therefore comes from ANT. Developed to understand the sociology of scientific knowledge and technology, ANT provides several concepts to assist the study of DEC in an integrated fashion (see Callon, 1986 for the key principles of ANT). The most important of these ideas is *translation*, which describes the way in which actors dynamically link together in a network (Law, 1992). Specifically it refers to the process by which different actors in a network (importantly including non-humans, such as the environment and technology) come to agree on common terms of reference, define their representatives and manipulate one another for cooperative or competitive aims (Callon, 1986). Through these negotiations, the network moves toward stability and so in the market transformation example, translation can help identify the agents (human or non-human) and processes which must be aligned for the desired policy change.

These translated networks are punctuated by "black-boxes", essentially concepts which actors in the network have agreed upon in previous negotiations. However these elements can be contested and by opening these boxes, debates can be reignited and insight gained (e.g. Latour, 1987; Murdoch, 1998). While the full implication of this principle will not be discussed here, the black-box concept demonstrates the appeal of ANT for an integrated approach to DEC, as it is clearly analogous to the "black-boxes" of engineering and physical science. Therefore the theoretical vocabulary of ANT—actors, networks, black-boxes and so on—has points of reference in both social and technical realms and this accessibility is further facilitated by its focus on tangible actors.

4.2. Practical considerations

There are also indications that an agent-based approach might work well in practice. ABM is an increasingly common technique for simulating complex social systems (Macy and Willer, 2002). By modelling the interactions between individual agents and their environment at a micro-level, ABM allows macro-social behaviours to emerge in might be called *generative* social science (Epstein and Axtell, 1996); this has parallels with the "bottom-up" modelling of some physical sciences as well. The advantage of this approach is that researchers can use their disciplinary expertise to specify a particular type of agent or environment within the model; however the goal is to examine not the individual agents themselves but the properties of the modelled system which emerge from the interactions of these agents with other types of agents, with their environment, all governed by simple micro-level rules. As such, ABM supports an integrated approach to DEC and has many potential applications including experimentation and the development of theory (Gilbert and Troitzsch, 1999).

The building blocks of such models are the same agents (actors) described by ANT above, providing congruence with theoretical discussions. Facilitated by object-oriented programming languages, and customised code libraries such as RePast or SWARM, the agent can be maintained as an accessible point of discussion throughout, allowing non-experts to understand the basic interactions driving the model. For example the EU FIRMA project on water resource management used the agent-based approach to allow researchers to approach a variety of stakeholders, expert and non-expert alike, and solicit their opinions on the structure and validity of the model (Warwick and Downing, 2003).

The proposed integrated framework, shown in Fig. 4, demonstrates the brief sketch discussed here by taking the comprehensive outline of van Raaij and Verhallen (1983) and reordering the multiple constituents of DEC into tangible agents. This satisfies the guiding principles of an integrated framework, by first giving a form which balances structure (arrangement of agents) and process (links between agents). Secondly, the framework works at both broad and narrow scales: for high-level consultation, the agents themselves are perhaps sufficient; for more specific disciplinary or policy applications, each element can be opened up as demonstrated by the sample household agent shown in Fig. 5. Thirdly, these features are supported by ANT and practical techniques from ABM. In other words, the flexibility of this framework sketch hopefully facilitates continued

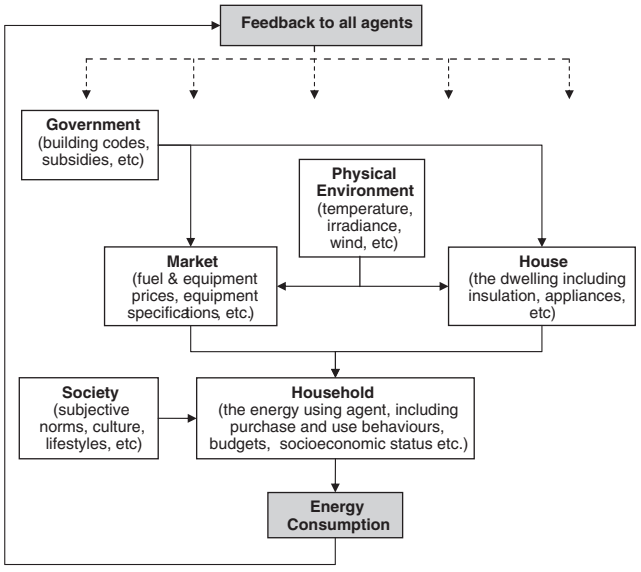

Fig. 4. An agent-based integrated framework for domestic energy consumption.

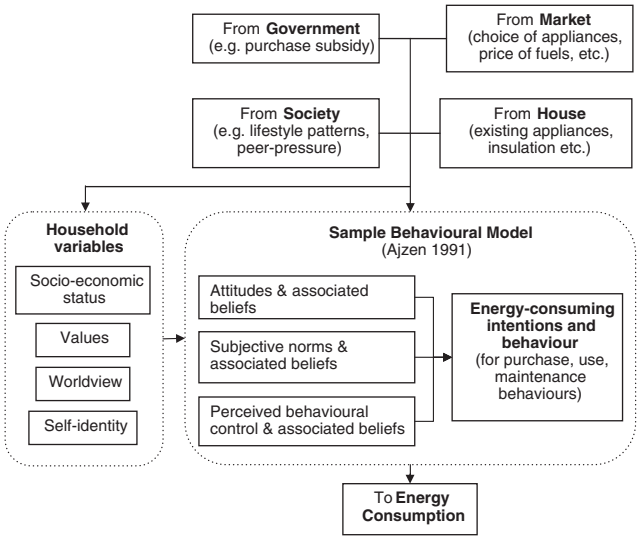

Fig. 5. An example of the household agent.

strong disciplinary research, while providing the common language needed for an integrated perspective.

4.3. Strengthening the proposed framework

If the benefits of an integrated approach are to be realised, the framework proposed here needs to be refined and introduced to those making decisions affecting DEC. This could be achieved in many ways but here, focus is placed on the potential role of the academic community as early champions of the concept.

At this preliminary stage, experimentation with the agent-based framework, its vocabulary and tools, is particularly important. The success of ANT itself demonstrates this, showing how a strong academic community has evolved from debate around its proposed vocabulary and forms of analysis (Callon, 1987; Collins and Yearley, 1992; Latour, 1987; Latour, 1999). One of the key concerns for such a project should be linking the theoretical and practical applications of the proposed DEC framework. In particular, it is difficult to translate the qualitative information contained within one agent into a quantitative form usable by the next. If sensible links between qualitative and quantitative elements cannot be made, there is a danger that complex processes (especially social and cultural ones) may be overlooked in favour of more accessible, arguably quantitative, parameters. Without opening these "black boxes", policy may well avoid any direct intervention with these aspects despite the fact that without such intervention, significant changes to the domestic energy system may not be possible.

In the UK, energy policy is typically developed in consultation with the academic community at early stages, as demonstrated by the role of the Performance and Innovation Unit in shaping energy white papers. Part of this process is sharing the lessons of research and examples of what works and what does not. Therefore preliminary efforts with an integrated DEC framework would do well to collect practical examples of success and failure. This experience can then form a valuable input to future policy makers.

Such input is more likely to have an impact if a strong community supports the proposed idea. Experience at the Environmental Change Institute on DECADE (a comprehensive DEC modelling project, see Boardman et al. (1995) for a description) has demonstrated that building such communities is feasible, though great care must be taken when bringing together people from various disciplinary backgrounds. These experts have strongly held beliefs about their disciplines and collaborating parties must take care not to reduce something as complex as values, for instance, to a simple number—not only to respect working partners but also to avoid oversimplification. The UK is fortunate in that the UK Energy Research Centre currently provides such an opportunity for experts from a variety of background to meet and work on DEC and other energy issues.

Developing an integrated approach may be seen by some as a Herculean task. However, the point of the framework sketch presented here is to enable practitioners to acknowledge the complexity of DEC without losing sight of the overall picture. Building upon theoretical contributions from ANT and practical techniques from ABM, this agent-based framework might provide the common language and structure needed to bring together existing expertise on DEC in an integrated perspective. However there is clearly much to be done if the validity of such an approach is to become widely accepted and influential in policy development.

5. Conclusion

This paper has examined various theories of DEC and shown that the issue requires a broad integrated perspective if effective changes in consumption are to be made. Disciplinary analyses, while valuable in their own right, often have too narrow a perspective to inform policy that seeks significant changes, such as the 60% reduction in CO_2 emissions sought by the UK government. In practice disciplinary measures remain popular, such as grant programmes for specific domestic renewable energy and energy-efficient technologies (e.g. the Major Photovoltaic Demonstration programme and Clear Skies programme). However the UK government has started to recognise that a subsidy or technological fix cannot solve complex energy problems and interest in an integrated approach is growing, through support for the UK Energy Research Centre and the anticipated integration of domestic renewables and energy-efficiency incentives in 2006.

As in the policy arena, integrated frameworks of DEC have had a limited influence in academic literature since their introduction over twenty years ago. Though a number of studies acknowledged the weakness of disciplinary models alone, articles proposing integrated frameworks have failed to spark a significant debate within the literature about how such an integrated approach might be structured or implemented. Nonetheless, the most influential studies of this field have been cited as justification for some diversification in disciplinary research. However, evidence presented here suggests that in recent years the disciplinary approach has become more popular in academia. This arguably sends the wrong message at a time when governments are trying to achieve more and more with their energy policies.

The difficulty is then how to correct this trend and combine diverse approaches to DEC research in a way that is accessible and meaningful to policy makers. The agent-based approach outlined here hopefully contributes to this process, by providing a common language for DEC and allowing experts to develop their work while acknowledging limits and interactions with other fields. The tools of ANT and ABM provide a solid foundation upon which to build such a framework though this paper has only provided a hint at what might be possible. Further research is clearly required, particularly on the links between qualitative and quantitative knowledge. This should be considered not a barrier but rather an invitation, as the policy challenges facing the UK merit a re-evaluation of how DEC is conceived in theory and practice.

Acknowledgements

The author would like to acknowledge the valuable input of an anonymous reviewer, as well as the support of Brenda Boardman and Sarah Darby at the Environmental Change Institute.

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