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Viable behavioural and technological energy-saving measures

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Both the natural and social sciences have been studying sustainable household consumption for a long time. However, cooperation between the two has been fairly uncommon. This paper argues that the disciplines should collaborate closely in designing more successful environmental policies on household energy use. It demonstrates how data from the natural and social sciences may be combined to identify energy-saving measures that are most likely to be successful, i.e., effective *and* acceptable (so-called viable energy-saving measures). Moreover, this study examined differences in acceptability of energy-saving measures between various socio-demographic groups. Differences in acceptability of behavioural and technological measures proved attributable not only to levels of environmental concern, but also to differences in income.

Between 1993 and 1999 a large interdisciplinary research programme on sustainable ‘household metabolism’ was conducted at the University of Groningen and the University of Twente (see Noorman & Schoot Uiterkamp 1998). The aim of the project was to examine the necessities, possibilities and barriers relating to the achievement of sustainable household metabolism from various scientific perspectives, such as science and technology, economics, spatial planning and psychosocial perspectives. In one of the subprojects, environmental scientists and social psychologists worked closely together to examine whether environmentally sustainable consumption patterns were also socially sustainable (Poortinga *et al.* 2001). The subproject involved the construction of scenarios for environmentally sustainable household energy consumption, which were subsequently evaluated for their acceptability by Dutch household representatives.. Respondents were also asked to evaluate the included energy-saving measures separately. This produced a dataset that combined natural and social scientific data on sustainable household energy use.

The present paper discuses some results of the subproject. We argue that cooperation is needed between environmental and social scientists to identify *viable* energy-saving measures, i.e., measures that are both effective and acceptable. We present assessments of the energy-saving potential of various measures and describe our findings on the acceptability of these measures. We also discuss group differences in the acceptability of various energy-saving measures. The paper concludes with an evaluation of the main findings. Before elaborating on the selection of viable energy-saving measures, we first describe important psychological differences between technological and behavioural measures, which may have consequences for their viability.

1. Viable energy-saving measures

Although both environmental and social scientists have been studying sustainable household consumption for a long time, collaboration between the two has been fairly uncommon. Environmental scientists tend to concentrate on the environmental impact of various consumption patterns, often without taking into account the social and psychological aspects underlying energy consumption (see e.g. Biesiot and Moll 1995; Vringer and Blok 1995; Wilting *et al.* 1999). Such studies reveal which behaviours should preferably be changed to achieve more sustainable consumption levels, but do not demonstrate whether and how such behavioural changes might be successfully introduced. On the other hand, many psychological studies of household consumption focus on behaviours that are not very interesting from an environmental perspective, such as refusing plastic bags in shops or purchasing recycled paper (Stern *et al.* 1997). These studies generally focus on how behavioural changes might be engendered and which changes may be acceptable. However, such changes will not carry much weight in the quest for sustainable consumption patterns if the focus is on behaviours that have only a minor effect on energy or material use, and it is questionable whether results of such studies may be generalised to behaviours with significant environmental impacts. Recent studies have shown that low-impact behaviours, such as recycling or purchasing environmentally friendly food products, are especially dependent on psychological factors such as environmental awareness, while high-impact behaviours, such as energy use, are typically dependent on socio-demographics like income and household size (e.g., Gaterslebenet *al.* 2002; Poortinga *et al.* 2002b).

Although both lines of research produce valuable information on sustainable and unsustainable consumption patterns, information on the energy-saving potential as well as on factors influencing behaviour and the acceptability of specific environmental policies is needed to design successful policies. Combining environmental and social science theories and methodologies could help to identify viable energy-saving measures, which may be defined as measures that are effective in saving energy as well as acceptable to those that have to adopt them.

2. Behavioural and technological energy-saving measures

Household energy use may be reduced in various ways. Often, a distinction is made between behavioural (e.g., switching lights off in unused rooms) and technological energy-saving measures (e.g., buying energy-efficient light bulbs). This distinction is relevant, since both types of measures have different psychological properties (Gardner and Stern 1996; Poortinga, *et al.* in press). Generally speaking, technological measures are perceived as being expensive, because they require initial investments that cannot be recovered instantly by their energy-saving potential. Moreover, people generally think it does not take much effort to adopt technological measures, and such measures hardly seem to reduce (and sometimes even increase) individual comfort. That is, one can perform the same behaviour as one did before, only using less energy. Energy saving automatically follows the purchase of technological innovations. In contrast, behavioural measures are often associated with additional effort or decreased comfort. For example, people think that a reduction in car use requires considerable adjustments to their lifestyle, which is time-consuming, requires additional effort and may also result in decreased comfort (e.g., Steg and Vlek 2001). Behavioural measures may be seen as cheap, as no initial investment is required. However, long-term energy savings only occur when new and persistent energy-saving habits are developed. For these reasons, technological measures are often believed to be more effective than behavioural measures (Costanzo 1986; Samuelson 1990; Gardner and Stern 1996). The underlying assumption is that increasing the energy efficiency of products will save more energy than trying to modify the use of existing, less energy-efficient appliances. As a result of the various psychological properties, there may be differences in the acceptability of technical and behavioural energy-saving measures. In view of these psychological properties, we expected that, on average, technological measures would be more viable, i.e., more acceptable and more effective, than behavioural measures (Hypothesis 1).

The various psychological properties of behavioural and technological energy-saving measures may also lead to differences in acceptability between various groups in society. The acceptability of various types of energy-saving measures may vary across these groups, as they may differ in terms of motivations, abilities and opportunities. For example, people differ in their willingness to take action to protect the environment, which may depend on the extent to which they are worried about the negative consequences of energy use (see e.g. Poortinga *et al.* 2002a). Hence, we expected that both behavioural and technological energy-saving measures would be more acceptable to people who are more concerned about the environment (Hypothesis 2). As behavioural measures are often considered time-consuming and are associated with effort or decreased comfort, they may be more difficult to adopt by households with limited time. Therefore, we expected that behavioural measures would be less acceptable to households with limited time, such as families with children and double-income households (Hypothesis 3). As technological measures are considered expensive and often require an initial investment, they are more affordable for those with a high income, but less easily adopted by low-income households. As a result, we expected that technological energy-saving measures would be less acceptable to low-income households than to high-income households (Hypothesis 4).

3. The Study

Selection of Energy-Saving Measures

The behavioural and technological energy-saving measures discussed in this paper were derived from a scenario study on sustainable household consumption (Poortinga *et al.* 2001). The scenarios for sustainable household consumption were based on the personal energy budget as proposed by Dürr (1994).[i] The construction of the scenarios involved a number of stages. First, average household energy use was calculated in various consumption categories, mainly using expenditure data and energy intensities (CBS 1999).[ii] The method used is described in more detail in Biesiot and Moll (1995), and Kramer *et al.* (1998). In addition indicating how much energy would have to be saved to arrive at a sustainable level of consumption, these figures indicated the categories in which energy saving was most significant. Second, the energy figures for various consumption categories were used to calculate the energy-saving potential of various behavioural and technological measures (see Poortinga *et al.* (2001) for a more detailed description of the calculations).[iii] The final stage of the construction of the scenarios involved selecting a set of energy-saving measures that reflect a sustainable level of household energy use. The environmentally sustainable scenarios and the individual energy-saving measures included in the scenarios were subsequently evaluated on their acceptability in the survey described below. Only the results relating to the individual measures are discussed here.

The Survey

Data for this study were collected in autumn 1999. Two thousand Dutch household representatives were invited to fill in a questionnaire on sustainable household energy use. A total of 455 respondents returned a completed questionnaire. The sample was not completely representative of the Dutch population (CBS 1999). Men, people with a high income, and people with a high level of education were slightly overrepresented (see Poortinga *et al.* 2001).

The survey comprised several questions on the *acceptability of various energy-saving measures*. These included thirteen behavioural and twelve technological energy-saving measures, which varied in their energy-saving potential (see table 1). The measures were presented with estimations of the energy-saving potential and any investment costs involved. The respondents were asked to indicate whether they thought the measures were acceptable on the following five-point scale: 1 'unacceptable', 2 'hardly acceptable', 3 'doubtful', 4 'acceptable', or 5 'very acceptable'.

The New Environmental Paradigm Scale (NEP) was used to measure *environmental concern* (Dunlap and Van Liere 1978). The environmental concern variable was calculated by adding up scores on 12 items, all of which could be answered on five-point scales. The reliability of the scale was found to be reasonable (Cronbach's alpha = .76). Respondents were subdivided into three environmental concern groups, using the tertiles as cut-off points. This resulted in groups with a low (N=152), average (N=146) or high level of environmental concern (N=153).

In the final part of the questionnaire, respondents indicated their age, type of household, income, and level of education. Based on these data, three age groups were distinguished: respondents between 20 and 39 years old (N=129), between 40 and 64 years old (N=248), and 65 years or older (N=69). Respondents were subdivided into three types of household: singles (N=152), couples without children (N=146), and families (N=153). Three income groups were distinguished: a monthly net income of less than 2500 Dutch guilders ('low', N=77), between 2500 and 4500 Dutch guilders ('average', N=189), and more than 4500 Dutch guilders ('high', N=174).[iv] Respondents were subdivided into three groups according to level of education: 'low', i.e., primary school only or basic vocational education (e.g., LBO) (N=66); 'intermediate', i.e., lower secondary education (MAVO) or intermediate vocational education (e.g., MBO) (N=130); and 'high', i.e., general secondary education (HAVO), university preparatory education (VWO), higher professional education (HBO) or university (N=244).

4. Results

Table 1 shows acceptability of and the estimated energy savings achieved by twenty-five behavioural and technological energy-saving measures. Strikingly, most measures were, on average, quite acceptable. The lowest mean acceptability score was just below the middle of the scale, indicating that even this measure was not considered to be really unacceptable. In accordance with our expectation, the average acceptability of technological energy-saving measures (3.92) was higher than that of behavioural energy-saving measures (3.68). Moreover, the average energy savings achieved by technological measures (4.75 GJ) were greater than that of behavioural measures (2.05 GJ). If we assume that viable measures should at least save 1 GJ of energy per year and should have an acceptability score of 3.5 or higher (see table 1)[v], the following six technological measures could be identified as viable: double glazing, energy-efficient heating system, house insulation, insulation of heating pipes, energy-saving light bulbs and an energy-efficient refrigerator. Four behavioural measures met the viability criteria: walking or cycling distances up to 2½ km, line-drying of laundry, taking shorter showers, and walking or cycling distances up to 5 km. These results indicate that, as expected (Hypothesis 1), technological measures were, on average, more acceptable and more effective than behavioural measures.

[TABLE 1 ABOUT HERE]

A number of multivariate analyses of variance (MANOVA) were conducted to examine whether various socio-demographic groups and groups differing in environmental concern differed in their acceptability judgments on various behavioural and technological energy-saving measures (see table 2). Environmental concern was found to be significantly related to the evaluation of the acceptability of behavioural energy-saving measures ($F(26, 870)=3.35$, $p<.001$).[vi] Univariate analyses showed that respondents with a high level of environmental concern evaluated almost all behavioural measures as more acceptable than those with a low level of environmental concern. However, no differences were found in the acceptability ratings for rinsing dishes with cold water and taking shorter showers, as all respondents considered this measure not very acceptable. The environmental concern groups also differed in acceptability ratings of almost all technological measures ($F(24, 868)=3.48$, $p<.001$). Again, these measures were more acceptable to respondents with a high level of environmental concern. No significant difference was found in the evaluation of the acceptability of buying energy-saving light bulbs, as all environmental concern groups found this an acceptable measure. These results confirm that both behavioural and technological energy-saving measures are more acceptable to consumers who are more concerned about the environment (Hypothesis 2).

[TABLE 2 ABOUT HERE]

Respondents of different ages evaluated behavioural energy-saving measures differently ($F(26, 870)=2.84$, $p<.001$). Older respondents considered turning off the pump of the central heating system in summer to be less acceptable than younger respondents. Older respondents found a maxium speed of 100 km/h on motorways and taking shorter showers more acceptable than younger respondents did. Respondents of different ages also evaluated technological measures differently ($F(24, 868)=2.43$, $p<.001$). Older respondents felt speed limiters and double-glazing to be more acceptable than younger respondents did, whereas younger respondents found cooking on gas more acceptable than older respondents.

Singles, couples and families also evaluated behavioural energy-saving measures differently ($F(26, 866)=2.84$, $p<.001$). As expected (Hypothesis 3), behavioural measures were less acceptable to families and couples. Singles found doing the dishes by hand, a smaller refrigerator, and a maximum speed of 100 km/h on motorways to be more acceptable than couples and families. Smaller differences were found for turning off the heating pump in summer, line-drying of laundry and taking shorter showers. Families found especially line-drying of laundry less acceptable than singles and couples. Singles, couples and families also differed in their evaluation of technological energy-saving measures ($F(24, 864)=1.84$, $p<.01$).. Couples and families found an energy-efficient heating system and insulation of heating pipes more acceptable than singles did. Singles thought that a speed limiter is more acceptable than couples and families did.

Income was significantly related to the evaluation of behavioural energy-saving measures ($F(26, 858)=2.43$, $p<.001$). Differences were found for doing the dishes by hand, smaller refrigerators, line-drying of laundry, a maximum speed of 100 km/h on motorways, walking and cycling short distances up to 5 kilometres, and to a lesser extent for car-pooling. All these measures were less acceptable to respondents with a high income. Technological energy-saving measures were also evaluated differently by the income groups ($F(24, 856)=2.33$, $p<.001$). As expected (Hypothesis 4), technological energy-saving measures were less acceptable to respondents with a low income than to those with a high income. High-income groups found an energy-efficient washing machine, insulation of heating pipes, an energy-efficient heating system, and to a lesser extent an energy-efficient refrigerator and house insulation more acceptable than low-income groups. These are all behaviours that need an initial investment. An exception was the speed limiter, which was more acceptable to lower incomes than to higher incomes.

Significant differences in acceptability ratings of behavioural measures were also found between respondents with different educational levels ($F(26, 852)=1.62$, $p<.05$). Doing the dishes by hand was more acceptable to respondents with a low level of education than for those with an intermediate or high level of education. Turning off the heating pump during summer was more acceptable to respondents with a high or intermediate level of education than to those with a low level. Respondents with different levels of education also evaluated technological measures differently ($F(24, 850)=1.78$, $p<.05$). Differences were found for applying radiator insulation, using the econometer, and to a lesser extent for an energy-efficient refrigerator, energy-efficient washing machine, insulation of heating pipes and an energy-efficient car. Respondents with a high level of education had higher acceptability ratings for all these measures.

The above differences in acceptability judgments were evaluated separately for the various socio-demographic and environmental concern groups. However, these socio-demographic variables may be interrelated, which did indeed prove to be the case in the present study. There were more couples and families in the 40-64 age group, and fewer families in the 65+ age group ($\chi^2(4)=53.3$, $p<.001$). As could be expected, level of education was related to income ($\chi^2(4)=100.7$, $p<.001$). Furthermore, singles had a lower average income than couples and families did ($\chi^2(4)=53.3$, $p<.001$). This is not surprising, as respondents were asked to indicate their total household income. Moreover, age was related to level of education and income ($\chi^2(4)=14.1$, $p<.01$ and $\chi^2(4)=15.4$, $p<.01$, respectively). The latter relationships were non-linear. In particular, respondents aged between 40 and 64 had a higher level of education, as well as a higher income, than the other income groups did. No differences in environmental concern were found between any of the socio-demographic groups.

[TABLE 3 ABOUT HERE]

As the socio-demographic characteristics were correlated, some of the differences reported above may be spurious. For example, differences between educational groups may be due to differences in income levels. In order to examine the unique contribution of each of the socio-demographic factors and environmental concern levels in explaining the acceptability of energy-saving measures, two regression analyses were conducted. The two regression models used the *average* acceptability of the behavioural energy-saving measures (Cronbach's alpha = .72) and the *average* acceptability of the technological energy-saving measures (Cronbach's alpha = .79) as their respective dependent variables, and environmental concern, age, income, household type and level of education as independent variables (see table 3). In total, 19% of the variance in the acceptability of behavioural energy-saving measurers could be explained by the independent variables. The acceptability of behavioural energy-saving measures was significantly related to environmental concern as well as income. That is, behavioural measures were more acceptable to respondents with a higher level of environmental concern, and less acceptable to respondents with a high income. Sixteen percent of the total variance in the acceptability of technological energy-saving measures could be explained by the independent variables. The acceptability of technological energy-saving measures was related to the same variables: environmental concern and income. Again, respondents with a high level of environmental concern found technological measures more acceptable. However, in contrast to behavioural measures, the high-income group evaluated technological measures as more acceptable than the low-income groups did. The results of the regression analyses again confirm the expectations that both behavioural and technological energy-saving measures are more acceptable to people with a higher environmental concern (Hypothesis 2), and that technological energy-saving measures are less acceptable to people with a low income than to those with a high income (Hypothesis 4). However, in contrast with our expectation, household type was not related to the acceptability of behavioural measures when we controlled for income and environmental concern (Hypothesis 3).

5. Discussion

The main aim of this study was to identify viable energy-saving measures, by combining data from natural and social sciences. We first assessed the energy-saving potential of thirteen behavioural and twelve technological energy-saving measures, and then examined to what extent these measures were acceptable to the public. We identified ten viable energy-saving measures, of which only four were behavioural. This indicates that, as expected, technological measures were more effective as well as more acceptable than behavioural measures.

Based on these results, it may be concluded that technological measures are generally more viable, and that policy-makers should focus especially on these measures. However, one should keep in mind that this may well be dependent on the specific measures included in the present study. Moreover, it is often overlooked that technology is also one of the main drivers of the ever-increasing energy use. During the past fifty years, household energy consumption has risen substantially as a result of the electrification of many household activities. Household energy use is still growing because consumers own and use more household appliances (Steg 1999; Gatersleben 2000). Likewise, the net effects of energy-efficiency measures are often overestimated. Gains in efficiency are often less than expected or even nullified by an increase in the level of consumption (Sanne 2000). For example, people tend to install energy-efficient light bulbs in places that were not illuminated before, or they do not switch off these lights. This so-called rebound effect has also been demonstrated with regard to water-saving showerheads and energy-efficient cars. An obvious way to reduce energy use is by simply not buying or using particular household appliances. Line-drying of laundry still requires less energy than the most energy-efficient tumble dryer.

As expected, various groups evaluated specific behavioural and technological household energy-saving measures differently. As a rule, older respondents, singles, low-income and low-education groups evaluated behavioural measures as more acceptable than younger respondents, families, and high-income and high-education groups. In contrast, technological measures were more acceptable for older respondents, couples and families, and for respondents with a high income and a high level of education than for younger respondents, singles, and low-income and low-education groups.

As expected, respondents with a higher level of environmental concern evaluated behavioural as well as technological measures as more acceptable than did those with a lower level of environmental concern. In addition, technological energy-saving measures were less acceptable to respondents with a low income than to those with a high income. The results of the regression analyses also suggest that differences in acceptability of the two types of energy-saving measures could, apart from environmental concern, mainly be attributed to differences in income. Although behavioural measures were less acceptable to households with limited time, household type did not significantly contribute to the explanation of the acceptability of behavioural measures.

An important dimension underlying acceptability may be how difficult it is to adopt certain measures (cf. Steg *et al.* 2002), which depends on the amount of time, money, or effort required to adopt these measures. For example, it was found that technological measures were generally more acceptable than behavioural measures. It may be argued that technological measures are generally easier to adopt than behavioural measures, as consumers can continue to behave as they are used to, only using less energy. Many technological measures only imply higher initial (investment) costs. However, technological measures may be more problematic and therefore less acceptable to low-income households because of financial constraints, e.g., because they cannot easily afford the initial investments required to buy energy-efficient appliances. In contrast, low-income groups might evaluate behavioural measures as more acceptable than high-income groups, even though some effort might be required to adopt such measures, as they will save money. Higher income groups might feel these cost savings are too low to compensate the effort needed to adopt the measures. Other measures may be problematic because they are time-consuming, and thus more difficult to implement for households having limited time, such as double-income households. Another relevant dimension may be whether or not consumers possess particular household appliances or whether they are already engaging in particular behaviours. In other words, as soon as people get used to something they find it hard to give up (Gatersleben 2000). For example, walking or cycling short distances does not make much of a difference to people who do not own a car, while those who do own a car may find it much more difficult to give up the privilege of using it. This may also be the reason why singles find a smaller refrigerator more acceptable than families.

The results of the present study should be interpreted with a degree of caution, given the relatively low response rate. Low response rates may result in selective samples, which may have a considerable influence on the results, especially on central tendencies. Although not completely representative, the sample was to a large extent comparable to the general Dutch population. Men, respondents with a high income and those with a high educational level were slightly overrepresented, which could imply that the average acceptability of some technological measures was somewhat overestimated, while the average acceptability of some behavioural measures was somewhat underestimated. Furthermore, the average level of environmental concern was fairly high in the sample. This is in line with other studies, which also revealed that the average level of environmental awareness in the Netherlands is relatively high (e.g. Inglehart 1995; Steg 1999). In the present study, we asked respondents to indicate whether they thought the measures were acceptable. It should be noted that acceptability is only an indication of intent, and these expressions may have been subject to so-called socially desirable answering. In addition, the relationship between intent and actual behaviour is generally weak, because of numerous personal and social, as well as economic and administrative hurdles (Ajzen and Fishbein 1980; Kok 1981). Nevertheless, the measures that were given higher acceptability ratings are more likely to be successful.

We argued that input from both the natural and social sciences is needed to make progress in the field of sustainable household consumption. The present study shows that these disciplines, which usually work in virtual isolation, can work together successfully. Expertise from both disciplines is needed to identify viable energy-saving measures. Environmental scientists can indicate which measures are effective in reducing household energy use by assessing their energy-saving potential, while social scientists can examine whether particular measures are also acceptable to the public. Furthermore, social scientists can examine differences in the acceptability ratings of energy-saving measures between various groups in society. The results of the present study reveal that the viability of energy-saving measures is indeed dependent on environmental concerns and individual factors, especially income. This suggests that various groups in society should be targeted differently in campaigns stimulating reductions in household energy use. For example, the present study revealed that fairly effective measures like purchasing energy-efficient appliances and insulating houses are less acceptable to people with a low income. This suggests that financial schemes, such as the 'energy bonus' (which was introduced in the Netherlands in 2000), can help stimulate the adoption of these energy-saving measures. However, financial incentives may be less effective when trying to encourage certain other types of energy-saving measures, in that they are only effective if the specific behaviour depends on price, which is not always the case. For example, Steg *et al.* (1999) have shown that the use of cars is more closely related to social and affective motives than to instrumental motives such as travel prices and speed. Therefore, future research should focus on the particular barriers which keep consumers from taking specific energy-saving measures.

NOTES

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[i] Dürr (1994) argues that sustainability will only be achieved if all energy comes from renewable sources. Moreover, he assumes an equal distribution of the available energy sources across the world. A sustainable level of energy use would then equal 47 GJ per person per year, or 108 GJ per household per year, assuming an average household size of 2.3 (CBS 1999).

[ii] Energy intensity is a measure of the amount of energy required to produce, transport and dispose of a product or service, which is bought for a certain amount of money. Energy intensity is expressed in MJ per currency unit (Vringer and Blok 1995; Biesiot and Noorman 1999). Energy use in a particular consumption category can then be calculated by multiplying the expenditures by the energy intensities in that category.

[iii] For all measures, the average primary energy savings per year were calculated in GigaJoules (GJ). Primary energy includes the energy needed for the production of electricity.

[iv] In December 1999, Dfl 100 was about € 45, £ 27 or $ 45.

[v] This is halfway between 3: 'doubtful' and 4: 'acceptable'.

[vi] The "p" value represents the likelihood that an observed difference is due to chance. In general, a difference is considered significant if this likelihood is smaller than 5%. In this case, the difference between the environmental concern groups in the acceptability of behavioural energy-saving measures was significant, as the likelihood that this difference was due to chance was less than 1‰.

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TABLE 1: Average estimated energy savings and average acceptability of twenty-five measures. *Note*: T = technological measure, B = Behavioural measure; Energy savings are expressed in cubic metres (m^3) for gas; kilowatt-hours (kWh) for electricity; litres for fuel; and Giga Joules (GJ) for total energy savings; the acceptability scale ranged from 1: 'unacceptable' to 5: 'very acceptable'.

TABLE 1

Energy-saving measure	Type	Estimated energy savings				Acceptability
		Gas	Electricity	Fuel	Total	
Switching lights off in unused rooms	B		110		0.40	4.60
Appliances not on stand-by	B		130		0.47	4.43
Double glazing	T	600			19.2	4.37
Energy-efficient heating system	T	235	100		7.88	4.30
Walking or cycling up to 2½ km	B			60	1.98	4.28
House insulation	T	150			4.80	4.26
Insulation of heating pipes	T	60			1.92	4.25
Turning off the heating system's pump in summer	B		100		0.36	4.07
Cooking on gas	T	-10	90		0.01	4.05
Line-drying of laundry	B		300		1.08	4.02
Energy-saving light bulbs	T		390		1.40	4.01
Applying radiator insulation	T	30			0.96	3.96
Energy-efficient refrigerator	T		470		1.69	3.92
Energy-efficient washing machine	T		150		0.54	3.87
Shorter showers	B		580		2.19	3.63
Walking or cycling up to 5 km	B			130	4.29	3.61
Econometer	T			18	0.60	3.58
Energy-efficient car	T			300	9.90	3.43
Car-pooling	B			120	3.96	3.42
Doing dishes by hand (disposing of dishwasher)	B	-30	150		0.42	3.34
Maximum speed of 100 km/h	B			35	1.16	3.34
Smaller refrigerator	B		370		1.33	3.12
Thermostat set at maximum of 18° Celsius	B	175			5.60	3.09
Speed limiter	T			35	1.16	3.07
Rinsing dishes with cold water	B	20			0.64	2.86

TABLE 2: Average acceptability of thirteen behavioural and twelve technological energy-saving measures for various respondent groups. *Note*: The scales ranged from 1: 'unacceptable' to 5: 'very acceptable'; + p<.05; * p<.01; ** p<.001

	Environmental Concern				Age				Household Type				Income				Level of Education			
	Low	Average	High		20-39	40-64	65+		Single	Couple	Family		Low	Average	High		Low	Average	High	
BEHAVIOURAL																				
Appliances not on stand-by	4.21	4.45	4.64	**	4.48	4.40	4.46		4.38	4.45	4.45		4.38	4.53	4.35		4.52	4.39	4.44	
Doing the dishes by hand (disposing of dishwasher)	3.03	3.46	3.54	*	3.10	3.39	3.57		3.75	3.37	3.01	**	4.09	3.40	2.97	**	3.76	3.33	3.20	+
Rinsing dishes with cold water	2.82	2.86	2.89		2.90	2.78	3.11		2.92	2.75	2.96		2.97	2.91	2.78		2.73	2.88	2.89	
Smaller refrigerator	2.87	3.12	3.37	*	3.05	3.10	3.29		3.60	3.02	2.88	**	3.44	3.20	2.89	*	3.32	3.02	3.11	
Switching lights off in unused rooms	4.40	4.57	4.81	**	4.66	4.56	4.59		4.51	4.60	4.64		4.58	4.64	4.59		4.62	4.66	4.57	
Turning off the heating system's pump in summer	3.79	4.14	4.28	*	4.34	4.05	3.65	**	4.04	3.90	4.25	+	3.94	4.06	4.14		3.62	4.06	4.19	*
Thermostat set at maximum of 18° Celsius	2.87	3.12	3.31	+	3.12	3.18	2.75		3.20	3.04	3.08		3.10	3.06	3.14		3.24	3.05	3.08	
Line-drying of laundry	3.78	4.06	4.20	*	4.05	3.97	4.10		4.10	4.15	3.83	+	4.40	4.06	3.81	**	4.18	4.10	3.91	
Shorter showers	3.49	3.68	3.75		3.44	3.68	3.84	+	3.63	3.49	3.78	+	3.66	3.66	3.61		3.70	3.68	3.61	
Car-pooling	3.16	3.35	3.73	**	3.24	3.46	3.65		3.44	3.54	3.28		3.68	3.51	3.21	+	3.70	3.28	3.42	
Maximum speed of 100 km/h on motorways	2.99	3.28	3.74	**	2.81	3.47	3.79	**	3.63	3.36	3.10	*	3.77	3.30	3.15	*	3.56	3.25	3.32	
Walking or cycling up to 2½ km	4.06	4.30	4.47	**	4.21	4.30	4.39		4.27	4.28	4.30		4.40	4.35	4.20		4.17	4.33	4.29	
Walking or cycling up to 5 km	3.37	3.60	3.86	**	3.53	3.66	3.63		3.66	3.56	3.63		3.95	3.69	3.41	*	3.70	3.57	3.61	
TECHNOLOGICAL																				
Applying radiator insulation	3.75	3.96	4.17	**	4.05	3.98	3.72		3.83	3.98	4.02		3.86	3.92	4.07		3.61	3.91	4.07	*
Cooking on gas	3.74	4.03	4.40	**	4.29	4.04	3.65	*	4.08	3.93	4.15		4.19	4.08	3.98		3.85	4.02	4.12	
Double glazing	4.23	4.32	4.56	*	4.21	4.44	4.43	+	4.27	4.48	4.34		4.24	4.32	4.49		4.32	4.37	4.39	
Energy-efficient refrigerator	3.73	3.82	4.20	**	3.96	3.94	3.79		3.87	3.97	3.91		3.80	3.84	4.10	+	3.61	3.89	4.02	+
Energy-efficient washing machine	3.63	3.78	4.18	**	3.92	3.88	3.76		3.74	3.97	3.87		3.71	3.79	4.06	*	3.58	3.88	3.94	+
Energy-saving light bulbs	3.93	3.96	4.14		4.04	4.06	3.82		3.90	4.01	4.09		3.81	3.99	4.13		3.77	4.01	4.09	
Insulation of heating pipes	4.14	4.21	4.41	+	4.27	4.26	4.19		4.09	4.32	4.29	+	4.08	4.20	4.41	*	4.05	4.22	4.33	+
House insulation	4.13	4.21	4.44	*	4.22	4.28	4.29		4.20	4.35	4.22		4.27	4.15	4.39	+	4.15	4.24	4.32	
Energy-efficient heating system	4.21	4.21	4.46	+	4.37	4.32	4.13		4.09	4.44	4.31	*	4.06	4.24	4.47	*	4.08	4.35	4.33	
Econometer	3.29	3.72	3.73	**	3.58	3.59	3.58		3.48	3.59	3.65		3.36	3.56	3.73		3.17	3.58	3.70	*
Speed limiter	2.70	3.12	3.37	**	2.64	3.18	3.45	**	3.37	2.99	2.93	+	3.47	3.11	2.84	*	3.36	2.87	3.09	
Energy-efficient car	3.19	3.39	3.71	**	3.34	3.46	3.48		3.50	3.38	3.42		3.29	3.37	3.58		3.21	3.30	3.55	+

TABLE 3: Results of two regression analyses. *Note*: Cells show standardized regression coefficients (β); T values are given in parentheses; * p<.01; ** p<.001; R^2 represents the proportion of variance in the dependent variables explained by the independent variables; Adj. R^2 is an adjustment for a possible overestimation of R^2.

	Energy-Saving Measures	
Independent variables	Behavioural	Technological
Environmental Concern	.38 (8.62)**	.35 (7.89)**
Age	.06 (1.39)	.03 (.62)
Income	-.19 (-3.56)**	.16 (2.88)*
Household Type	-.03 (-.66)	-.01 (-.11)
Level of Education	.02 (.30)	.07 (1.41)
R^2	.20	.17
Adj. R^2	.19	.16

Energy saving mechanisms have a fundamental role in evo-lutionary processes, and necessarily involve thermodynamic considerations. Thermodynamic approaches to evolutionary pro-cesses may be traced to Lotka (1922), who proposed that evolution and biological systems are mass and energy dependent, in ux and driven to increase.Â Indeed, given their presence in non-biological systems as a basin of attraction and mechanism for self-organized complex behavior, it is easy to speculate that they play a critical role in the primordial origins of life itself, although further analysis is beyond the scope of this paper. All energy sources have some impact on our environment. Fossil fuelsâ€"coal, oil, and natural gasâ€"do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions. However, renewable sources such as wind, solar, geothermal, biomass, and hydropower also have environmental impacts, some of which are significant. The exact type and intensity of environmental impacts varies depending on the specific technology used, the geographic location, and a number of other factors. Our results show how energy-saving technological change varies across countries over time and the extent to which it contributes to economic growth in 12 OECD countries from the years 1978 to 2005. KEYWORDS: Non-neutral technological change; capitalâ€"laborâ€"energy substitution; growth ac-counting. JEL CLASSIFICATION: E23, O33, O44, O50, Q43, Q55.Â Measuring energy-saving technological change is challenging. Environmentally friendly techno-logical change is typically measured in the literature using data on research and development (R&D) and patents (Popp, 2019). These measures, however, have some drawbacks. R&D spending is a mea-sure of an input into the innovation process rather than its outcomes. Although this method of creating energy is relatively inexpensive, our planet pays the price â€" carbon dioxide, sulfur dioxide and nitrogen oxides are just a few of the byproducts that come from traditional methods of power generation. Carbon dioxide, which accounts for the majority of all airborne pollution, is a greenhouse gas.Â When you opt to cut back on energy use, you also help conserve limited natural resources that would otherwise be used to power the power plants. Less demand for energy creates less demand for harvesting fossil fuels. Turning off the lights at night or washing clothes in cold water can save trees, coal, natural gas and more. From an economic standpoint, itâ€™s critical to conserve our finite resources.