Energy Efficiency Series

International Energy Agency

ENERGY EFFICIENCY POLICY AND CARBON PRICING

INFORMATION PAPER

Lisa Ryan, Sara Moarif,
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This information paper was prepared for the Energy Efficiency Working Party in August 2011. It was drafted by Lisa Ryan, Sara Moarif, Ellina Levina and Richard Baron of the Energy and Environment Division and the Carbon Capture and Storage Unit. This paper reflects the views of the International Energy Agency (IEA) Secretariat, but does not necessarily reflect those of individual IEA member countries. For further information, please contact Lisa Ryan of the Energy Efficiency Unit at: lisa.ryan@iea.org

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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Table of Contents

List of tables

List of boxes

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Summary

The main message of this paper is that while carbon pricing is a prerequisite for least-cost carbon mitigation strategies, carbon pricing is not enough to overcome all the barriers to cost-effective energy efficiency actions. Energy efficiency policy should be designed carefully for each sector to ensure optimal outcomes for a combination of economic, social and climate change goals.

This paper aims to examine the justification for specific energy efficiency policies in economies with carbon pricing in place. The paper begins with an inventory of existing market failures that attempt to explain the limited uptake of energy efficiency. These market failures are investigated to see which can be overcome by carbon pricing in two subsectors – electricity use in residential appliances and heating energy use in buildings.

This analysis finds that carbon pricing addresses energy efficiency market failures such as externalities[1] and imperfect energy markets. However, several market and behavioural failures in the two subsectors are identified that appear not to be addressed by carbon pricing. These include:

- Imperfect information
- Principal-agent problems
- Behavioural failures

In this analysis, the policies that address these market failures are identified as complementary to carbon pricing and their level of interaction with carbon pricing policies is relatively positive. These policies should be implemented when they can improve energy efficiency effectively and efficiently (and achieve other national goals such as improving socio-economic efficiency).

The paper complements the IEA paper *Combining Policy Instruments for Least-Cost Climate Mitigation Strategies*, which provides policy guidance on how to assess the need for supplementary policies for energy efficiency and renewable energy with existing carbon pricing.

[1] Externalities are the negative or positive effects of an action, taken by one party, on another who did not participate in the action. Pollution and climate change arising from less than optimal use of energy by some parties are classic examples of externalities.

Introduction

The need to guard against the risk of rapid climatic change and renewed concerns about energy security have drawn increased attention to energy efficiency policy. The International Energy Agency (IEA), among others, puts energy efficiency at the core of the policy response to rising energy-related carbon dioxide (CO_2) emissions. Many countries have strategies in place to mitigate CO_2 emissions and carbon pricing is increasingly playing a role. Energy efficiency policies tend to focus on measures such as information and awareness-raising activities, energy performance standards and labelling, and financial supports. This paper examines the justification for energy efficiency policies in economies with carbon pricing in place and the potential for interaction between the two kinds of policies.

The medium-term focused *World Energy Outlook 2010* shows a substantial contribution of energy efficiency to CO_2 emissions reduction between now and 2035. In its 450 Policy Scenario 71% of the global emission reductions would come from energy efficiency improvements in 2020, and roughly 50% in 2035 (IEA, 2010b).[2] The BLUE Map scenario featured in *Energy Technology Perspectives 2010* (IEA, 2010a), in which global energy-related CO_2 emissions would be cut by half by 2050, shows energy efficiency improvements delivering the largest share (38%) of CO_2 emission reductions by that date.

Beyond the thorough analysis behind these and other projections supporting the central role of energy efficiency, there is also a general recognition that energy efficiency "makes sense". It should help lower energy bills for consumers in the near term. By lowering overall demand for energy, it also prepares consumers for the rise in energy system costs that is to come if we are to move away from fossil fuel use. As an example, decarbonisation of the power generation sector by 2050 will require an increased use of renewable energy sources, nuclear, carbon capture and storage, smart grids and meters, and other technology solutions that will add to the capital cost of delivering a unit of electricity to consumers. Cutting electricity consumption through enhanced efficiency of equipment and appliances is indeed a prerequisite for the social acceptability of the cleaner, yet initially more expensive energy system needed to deal with climate change. There are also other non-carbon-related reasons to improve energy efficiency, such as security of energy supply, electricity load management, increased productivity, and competitiveness issues, that are not dealt with here but reinforce the need to ensure that the energy efficiency potential is exploited.

Putting energy efficiency potential at the core of an energy strategy to address climate change is only a first step. The second step is to identify the most cost-effective ways to implement such efficiency improvements. The IEA has published a set of concrete energy efficiency policy recommendations targeted to specific sectors, based on the recognition that barriers stand in the way of consumers making the rational, least-cost choice for their energy usage. These policies, if properly implemented, could help consumers and society to achieve the same level of energy service at lower cost. If energy efficiency policies are well designed to encourage not only an increase in the purchase of more energy efficient equipment, but also a reduction in their operation (the rebound effect), then the ensuing lower energy needs would, in most cases, deliver lower CO_2 emissions.

[2] The 450 policy Scenario sets out the energy pathway consistent with the goal of limiting the global increase in average temperature to 2°C, which would require the concentration of greenhouse gases in the atmosphere to be limited to around 450 parts per million of carbon dioxide equivalent (CO_2–eq.).

Standard environmental economic theory, however, questions the role of energy efficiency policy in climate mitigation strategies. This view is based on the fundamental principle that a carbon price set across the whole economy is the most cost-effective, welfare-maximising or pareto-efficient way to guide all agents – consumers and producers alike – away from energy-related CO_2 emissions. The assumption is that such a price could also address all of the barriers associated with energy efficiency (such as environmental and other externalities) and would naturally prompt improvements in energy efficiency. This view would recommend that other policies are redundant in areas where the carbon price is operational and should be removed unless governments are pursuing policy objectives other than climate change mitigation.

The response to this view is that a number of pervasive barriers to increasing the energy efficiency potential may not be addressed through a carbon price. Energy efficiency policies are needed to remove barriers (other than externalities) to rational, cost-effective energy choices and would enhance the cost-effectiveness of a carbon price signal. Also, the carbon price may be set sub-optimally in many sectors or not apply to some sectors and therefore not deliver the energy efficiency improvements required. Well-designed energy efficiency policy interventions would ensure that the carbon price signal is effectively transmitted all along the energy production and consumption chain. These policies avoid imposing an additional energy cost on consumers who have limited flexibility to adjust to the price signal. With effective energy efficiency policies in tandem with a carbon price, more emission reductions would be achieved with a given price signal. In the case of a cap placed on carbon emissions, the energy efficiency policies will not improve the level of emissions reductions achieved, but would lower the cost of achieving this level. In either event, energy policy makers should therefore make use of energy efficiency in combination with carbon pricing for their climate mitigation objectives.

This last view is the starting point for this paper; the analysis does not, however, take for granted that policy makers have "got it right" so far. Rather, it seeks to clarify what role energy efficiency policy can play to deliver a least-cost climate mitigation strategy, *i.e.* the appropriate role for energy efficiency policy in a world with carbon pricing.

In the energy sector of many IEA countries today, governments have implemented energy efficiency policies such as standards, labelling, awareness-raising activities, and fiscal policies. These policies can interact with climate change policies through overlap or duplication, with either positive and/or negative effects. These complex interactions are the subject of a lively debate as various groups argue for different policy instruments going forward.[3]

The purpose of this paper is to help policy makers in the design of effective and least-cost energy efficiency policy in the context of price-based climate policy. It is important for policy makers to examine whether or which energy efficiency policies are needed in the presence of economy-wide carbon pricing. It is worthwhile checking the complementarity of carbon and energy efficiency policies to reduce administrative and cost burdens imposed on individuals, firms and policy makers themselves. The questions this paper aims to answers include:

- What are the barriers to energy efficiency that cannot be addressed by a carbon price? Which policy interventions are required to overcome such barriers?
- What is the impact – the interactions with carbon pricing, the costs and effectiveness – of those targeted policy measures taken to remove these barriers?

[3] Part of the debate is motivated by the distribution of the cost of policy to reduce CO_2 emissions: should appliance or car manufacturers be tasked to deliver cleaner equipment, or should the carbon price be the sole driver of change? Cost distribution is not directly addressed in this paper.

To facilitate analysis, we define climate policy instruments as those that put a price on energy-related CO_2 emissions, either via a tax, or via a carbon-trading instrument. The discussion largely focuses on the micro-economic picture, *i.e.* the behaviour of individual economic agents faced with different energy choices and a carbon price signal. The macro-economic aspects will not be considered in detail.

There are important consequences for the outputs from this research. The energy efficiency policy gaps in the presence of carbon pricing will be identified and this should enable policymakers to better design policy packages that simultaneously address energy efficiency and greenhouse gas (GHG) mitigation targets. As policymakers utilise carbon markets more widely to mitigate greenhouse gas emissions, it is important to appreciate the scope and limits of their impact in addressing energy efficiency challenges.

This paper is structured as follows: the next section presents the methodology used; the third section provides a theoretical discussion of barriers to energy efficiency; the fourth section examines the empirical evidence of barriers to energy efficiency and policies to overcome them in the end-use residential electricity sector; the fifth section does the same for heating energy use in buildings; and the final section summarises and concludes.

Methodology

This paper addresses the questions outlined above using a qualitative approach. The authors support the view that energy efficiency policies should only be implemented when they (i) address a market failure and (ii) are complementary to other policies in that no two policies address the same aspect of the same market failure (in line with CoA, 2008; Jaffe and Stavins, 1994). Therefore the approach taken in this paper is to examine whether energy efficiency policies fulfil two conditions: a "necessity" condition and a "good design" condition.

We examine, theoretically, and using examples in particular sub-sectors, whether additional energy efficiency policies are necessary when a carbon price is in place, by testing whether energy efficiency policies meet either one of the following necessity conditions:

- A market failure exists that is not already addressed through carbon pricing and that can be addressed by government intervention;
- The carbon price, for reasons such as lack of political or public acceptance, is suboptimal; *i.e.* it does not sufficiently address the externalities associated with energy use to overcome other market failures that prevent the take-up of otherwise cost-effective measures.

Once it is established that certain energy efficiency policies meet the necessity condition, these policies must then fulfil the good design conditions:

- They deliver emissions reductions or energy savings at a cost that is lower than the market price for CO_2;[4]
- The policy interactions with the carbon price are complementary, that is, the enhance the carbon price signal and bridge gaps where the price signal is limited (for example, due to the inability to pass through costs). Two of the criteria of Oikonomou and Jepma (2008) for complementary policy interactions are applied, namely:
  - **Effectiveness:** The policies enhance the likelihood of achieving their environmental objectives.
  - **Efficiency:** The interacting policies achieve pollution abatement at least cost, following a cost and benefit assessment (including indirect, direct and transaction costs).

This work is carried out in three steps.

Step 1: Identify the main market failures associated with implementation of energy efficiency. Although energy efficiency market failures are widely discussed in the literature, the discussion often focuses on one particular aspect or one sector. We think it of value to present the market failures relating to energy efficiency together in the context of carbon pricing in a theoretical section.

Step 2: Examine the extent of market failures in two areas in the buildings sector where there is evidence available – (i) appliances electricity use (section 4) and (ii) heating energy use (section 5) – associated with energy efficiency. There is not a large amount of ex-post analysis of the efficiency of energy efficiency policies. However, we do find some reports on the costs and effectiveness of policies addressing energy efficiency in appliances electricity use and buildings heating energy use. We therefore focus on these two areas in this first piece of analysis on this topic.

[4] This already indicates that the carbon price is not fully unlocking all energy savings potentials.

Step 3: Consider the policies used to improve energy efficiency in individual sectors (*i.e.* the residential appliances and heating use in buildings sectors) **to see whether they fulfil both the necessity and good design conditions**. This means answering four questions:

- Do the policies address the market failures in the particular sector?
- How effective are the policies in achieving energy savings?
- Are they efficient in terms of least cost and positive benefit-cost ratio?
- How do the policies interact with a carbon price?

This last is the core question addressed. We also try to consider the wider impacts of energy efficiency and carbon pricing policies such as the rebound and free-rider effects.

The methodology relies on methods developed by other researchers in this area. Several pieces of work have examined environmental policy interaction at a general level (OECD, 2007); in recent times, the interaction between international and national policies, particularly since the advent of the European Emission Trading Scheme (EU ETS) has also been researched (see Sorrell and Smith, 2001 and OECD, 2011 for example). This work has resulted in recommendations on good practice in the design of policies to avoid negative interaction effects. Some of these provide criteria against which the energy efficiency polices identified as addressing market failures in the appliances sector can be assessed.

Boonekamp (2006) examines the literature on what factors prompt energy efficiency actions being undertaken. He finds that there are four market failures that must be overcome. Boonekamp examines qualitatively the interaction between policies by examining which of the four market failures is addressed by individual policies. If two policies address the same market failure then it is assumed that the combined effect is less than the sum of the individual policies. This is considered to be an "overlapping" or "counterproductive" situation. The opposite case is when two policies complement each other and address completely different market failures with the result that they are considered to reinforce each other. An optimum mix of policies is when all conditions or market failures are addressed / satisfied; the policies complement each other; one policy influences more than one market failure and policies are introduced in the most effective order.

Oikonomou and Jepma (2008) handle climate and energy policy interaction in a similar manner. They divide the areas of possible policy interaction into 10 categories.[5] Their next step is to evaluate the policy interaction in each category using five criteria: effectiveness, efficiency, impacts on market and energy prices, impacts on society, and innovation. Similarly to Boonekamp, policy interactions are assessed under each criterion as positive, negative or neutral by comparing them with a baseline of standalone non-interacting policies. A basic assumption in applying this methodology is that full information on the parameters and impacts of various individual policies is available; this assumption may not hold true in many cases.

Since detailed data on the sectors examined here are not available, we examine the interactions of energy efficiency policies and carbon pricing using a similar methodology to that of Boonekamp. We set out which market failures are addressed by each policy and then judge whether a policy addresses the same market failure as carbon pricing or another energy efficiency policy. A qualitative analysis follows.

[5] The types of policy interaction identified are the following: national (horizontal); international (vertical); same policy context (internal); different policy context (external); operational; sequencing; trading; integration; separation (stand-alone measures); one way fungibility; double fungibility.

Barriers to Energy Efficiency

This discussion of the barriers to energy efficiency should help readers understand why energy-efficient technologies and practices that are apparently cost-effective are not more widely used. This is useful in determining the extent to which carbon pricing can address this problem.

Energy efficiency barriers have been categorised as one of three types: economic, behavioural and organisational (O'Malley *et al.,* 2003). Jaffe and Stavins (1994) argue that barriers to energy efficiency can be separated into non-market failure barriers (private information costs, high discount rates, heterogeneity among potential adopters, hidden costs, access to capital) and market failure barriers (imperfect information, principal-agent relationships, split incentives and adverse selection). Behavioural science uncovers other barriers, such as the form of information available, the credibility of information sources, inertia, and culture or values. Organisational theory indicates another barrier: the power or status issue within an organisation associated with energy efficiency and its management.

Economists make the case for public policy intervention where there is market failure under certain conditions, but not necessarily otherwise. In the absence of market failure, limited investment in energy efficiency may simply be rational, given the risk-adjusted rate of return on an investment under current economic conditions and hidden costs (Sorrell *et al.*, 2004). Economists argue that public policy should aim not just for energy efficiency, but economic efficiency, and thus also contribute to an optimal allocation of resources overall, including government resources (Jaffe and Stavins, 1994). The cost associated with removing non-market failure barriers to energy efficiency would mean that even if doing so achieves a high level of energy savings, this may not contribute to economic efficiency and may not be socially optimal (Jaffe and Stavins, 1994).

Barriers to energy efficiency caused by market failures most clearly require public policy intervention; these are examined generally and then more specifically for the subsectors electricity use in residential appliances and space and water heating energy use in buildings in the subsequent sections.

Market failures and energy efficiency

Market failures occur when one or more of the conditions necessary for markets to operate efficiently are not met. In the context of energy efficiency, a market failure would imply that more energy is being consumed for the associated level of service than a rational allocation of resources would justify, in light of consumer and producer preferences. Given the list of ideal conditions necessary for markets to operate perfectly,[6] market failures are pervasive; hence public intervention is not justified solely by their existence, as discussed above, but also by whether the benefits of intervention exceed the costs. Transaction cost economics and behavioural economics also add to the discussion on barriers to energy efficiency, bringing more realistic models of economic organisation and decision making to the restrictive assumptions and idealised markets of orthodox economics (Eto and Golove, 1996; Sorrell *et al.,* 2004).

[6] We define perfect markets when resources are allocated efficiently and the following conditions are satisfied: (i) all parties have access to all information; (ii) actors behave rationally; (iii) there is free market entry and exit; (iv) no party has market power to set prices.

Market failures can fall in four general categories (O'Malley, Scott and Sorrell, 2003; Sorrell *et al*., 2004): Imperfect competition, incomplete markets (incomplete property rights and externalities), imperfect information and asymmetric information (also known as information failures).

There is ample evidence of market failures with respect to energy efficiency in the literature (Geller and Attali, 2005; Sorrell *et al*., 2004; Eto and Golove, 1996). The discourse on market failures with regard to the energy efficiency gap tends to focus on imperfect information and principal-agent problems, as these factors appear most relevant in explaining why users are not investing in technologies and measures that make financial sense under current economic conditions.

The discussion of market failures in energy efficiency in this paper therefore focuses on these energy efficiency market failures, energy market failures, which are the main target of carbon pricing, and behavioural failures:

- Imperfect information (information failures);
- Principal-agent problems;
  - Asymmetric information including adverse selection and moral hazard
  - Split incentives
- Externalities (energy market failures);
- Behavioural failures (bounded rationality).

Imperfect information

Insufficient, inaccurate or costly information on the energy performance of different technologies, and on the costs and benefits of energy efficiency measures, leads to sub-optimal decisions by consumers and investors, and an under-investment in energy efficiency. Energy efficiency is often one of several features of a product or service, as is the case with vehicles, appliances, or home retrofits. In this case, there is no separate market for energy efficiency, which is bundled together with other product attributes (IEA, 2007).

Accurate and sufficient information is difficult to obtain easily (at little cost) since energy efficiency comprises a wide range of products and services that are not always separately available. The market thus doesn't always produce or transmit sufficient information to allow for optimal energy-efficiency investment decisions.

Such informational failure can in part be due to the cost of obtaining information as well as the public good attributes of information (Jaffe and Stavins, 1994). Information has characteristics which resemble that of a pure public good: it is non-rivalrous in consumption (its use by one person does not reduce its availability to another person) and non-excludable in ownership (it is difficult for the entity producing information to exclude people from its benefits or to capture all the benefits of its use). Because providing generic information on the advantages of energy-efficient motors would not benefit a given motor manufacturer, customers may receive information about the advantages of a particular model, but not on energy-efficient motors in a product class. A consumer would thus have insufficient information on the quality of a motor's energy efficiency relative to others (Sorrell, 2004).

Principal-agent problems

We use the term principal-agent problem to describe market failures that encompass split incentives and asymmetric information. Agency theory and the principal-agent relationship are useful to describe a situation in which one party (the principal) delegates work, for example provision of a good or service, to another (the agent), who performs that work. A classic example is the landlord-tenant problem where the landlord is the agent and the tenant is the principal. Two problems can occur in such a relationship: the principal and agent have conflicting goals, desires or incentives (split incentives), and it is difficult or expensive for the principal to verify what the agent is actually doing (asymmetric information) (Eisenhardt, 1989).

This is useful for understanding market barriers to energy efficiency, as a principal-agent relationship can occur in various contexts. It can refer to landlords and tenants, both in the residential or commercial sectors. The relationship can also be present between providers of television set-top boxes and users; between beverage and food distributors and property owners (*e.g.* vending machines or grocery stores); or between the owner of a building (principal) and a sub-contractor (agent). Principal-agent problems also often occur within firms due to organisational arrangements, which can, for example, maintain separate budgets for capital investments on energy-using equipment and operational energy costs that are administered by two distinct divisions.

The IEA (2007) used a range of case studies to assess the scale of the principal-agent problem. The authors estimate that 30% of primary residential energy is affected by principal-agent problems. The study classifies the principal-agent situation into four cases (Table 1). In these four situations, only case 1 does not represent a principal-agent problem since the end-user chooses both the technology and pays the energy bills. In the other three cases, either the end-user (the principal) does not choose the technology or does not pay the energy bills or both; therefore the principal-agent problem applies.

Table 1: Four situations of apportionment of technology choice and energy payments: three principal-agent problems (shaded)

Energy technology purchase → Energy use ↓	End user can choose technology	End user cannot choose technology
End user pays the energy bill	Case 1	Case 2
End user does not pay the energy bill	Case 3	Case 4

Asymmetric information

Asymmetric information is a special kind of informational failure in which parties to a transaction, such as the purchase of a good or service, have access to different levels of information on the subject of the transaction. For example a manufacturer may know more about the actual energy performance of a product, such as a refrigerator, than the purchaser. Asymmetric information leads to two further kinds of market failures: adverse selection and moral hazard.

Adverse selection

Adverse selection occurs when one party in a transaction has information not easily available to the other party *before* the purchase or sale of a good or product occurs. Adverse selection can have an adverse effect on the buyer, seller or both. Adverse selection could negatively affect the customer in a situation where a product manufacturer who knew his product was less efficient than it could be might try to hide the reality of its (weaker) energy performance in comparison with others. While it could be possible for a consumer to distinguish between two different types of products offered even under conditions of adverse selection, this implies a cost in terms of the time taken to obtain, compare and assess information. Alternatively, the producer of an energy-efficient refrigerator, for example, would be negatively impacted if he could not communicate how favourably the energy performance of his product was compared to that of other similar refrigerators. A customer, even one who consciously cared about energy efficiency, energy prices and the refrigerator's running costs, would thus find it difficult to make a cost-effective purchase decision. This in turn could discourage the production of energy-efficient refrigerators.

Moral hazard

Moral hazard refers to a situation in which one party in a transaction's actions are unobservable to the other, leading the first party to act opportunistically *after* a contract for buying or selling a good or service is signed. There is an incentive for the unobserved party to take advantage of the situation for their benefit, as the interests of the two parties may differ. This can be illustrated by the example of an architect or engineer hired to design or install components in a building that would improve energy efficiency. Since the person hiring the architect or engineer cannot verify the time and effort spent on looking for the most efficient design options or technologies, the latter has no incentive to make the most effort (Bleischwitz and Anderson, 2009).

Split incentives

Split incentives occur when the two parties to a transaction have different goals or incentives, again the main example in the energy efficiency literature being the "landlord-tenant problem". Split incentives may be seen as a result of asymmetric information. It can also be understood as a classic principal-agent problem where the benefits of an investment (*e.g.* lower energy costs) do not accrue to the party making the investment. The landlord-tenant example is often given since the tenant most often pays the electricity bill but does not select and install major appliances affecting energy use, such as refrigerators and washing machines, or heating systems.

Split incentives also occur where tenants do not pay for electricity, but where this is included in the rent. In this situation, though landlords may have an incentive to purchase energy-efficient appliances, the tenant has no incentive to control energy-use.

Externalities

Externalities are the costs or benefits of an action that are borne by parties who are not participants in the action. The negative externalities associated with the generation and use of energy, for example excessive GHG emissions and their associated impacts, impose a cost on society and decrease social welfare. If the costs of these negative environmental consequences are not borne by those who produce and consume energy, more energy will be used than is socially desirable, while the level of energy efficiency will be below that which is socially desirable. Fiscal or market instruments that increase the price of energy or of pollutants associated with energy use (such as GHG emissions) can act, at least partly, as a means to internalise the cost to society of negative externalities.

It is also important to note that energy prices, even when they incorporate the price of carbon, still may not adequately reflect the true cost of energy use to the society. Since energy efficiency choices often involve decisions that trade off initial capital costs against uncertain lower future energy operating costs, the expected energy price has a significant influence on the outcome of the investment analysis. The level of carbon price needed to overcome externalities associated with energy use and production are not considered in this paper. Instead, an ideal case is assumed where the carbon price is sufficient to "deal with" externalities so that attention can be focused on the question of the necessity for complementary energy efficiency policies.

Box 1: The Rebound Effect

As energy consumers save on energy cost through energy efficiency, they may spend their savings on other energy-intensive activities, or increase their demand for the new service, thereby countering the potential savings of energy. This is called the rebound effect. Earlier work (IEA, 2005) has found the direct rebound effect to be limited to between 10% and 30% in the residential sector. Carbon pricing limits the rebound effect, since the added carbon cost paid by energy consumers reduces the monetary savings achieved through energy efficiency and therefore the demand for more energy. Further, in the case of a cap-and-trade instrument, the enforcement of the cap would prevent any rebound effect from undermining the environmental results delivered by energy efficiency. However, more work is needed to measure the indirect and macroeconomic effect of energy efficiency policy, particularly in the industrial sector and in developing countries where available data have been limited.

Behavioural failures

While the existence of negative externalities may justify public intervention to correct market failure, it does not necessarily explain the energy efficiency gap; *i.e.* why users are not adopting energy-efficient technologies that should be to their own economic advantage at current prices (O'Malley, Scott and Sorrell, 2003; Jaffe and Stavins, 1994). Bounded rationality is a behavioural failure in that decision-makers do not make choices rationally, as generally assumed in classical economic theory. Energy equipment purchasers and users may have "limitations of both knowledge and computational capacity" (Simon 1997) that affect their consumption of electricity by appliances. The evidence that consumer decisions are not always perfectly rational is quite strong (Gillingham *et al.*, 2009). Behavioural failures may be relevant as an explanation for irrational behaviour and choices, and may reinforce existing market failures.

Electricity End-use in the Residential Sector

Residential electricity consumption has been growing at an average of 3.4% globally between 1990 and 2006. It is mainly consumed in cooking, water heating, space heating, space cooling, lighting, and the use of appliances and electronic equipment. The share of electricity in each end-use category varies among countries depending on country circumstances, particularly climatic conditions and economic development level.

This section examines appliances energy efficiency and electricity use. Appliances consumed on average 15% of total electricity in IEA countries and nearly 50% of residential electricity in IEA countries in 2006. The amount of electricity consumed by appliances has risen by 2.7% annually in IEA countries,[7] although many countries have policies in place to address energy consumption by appliances.

Previous IEA reports have highlighted the need for both energy efficiency policies and carbon price signals in the appliances sector. The limits to the impact of carbon prices on end-use electricity consumption are discussed briefly in *Gadgets and Gigawatts: Policies for Energy Efficient Electronics* (IEA, 2009). That analysis notes that carbon prices may not address energy efficiency barriers because of: the low price elasticity of demand; the low share of electricity spending in household budgets; the lack of time available to consumers when they are purchasing a replacement appliance or piece of equipment; and the split incentive issue in which neither manufacturers nor consumers have the possibility to choose electronic components within assembled products.[8] This section will discuss these issues in more detail and explore further the impact of carbon and energy prices on energy efficiency in the electricity end-use sector – namely in the purchase and use of appliances. Evidence from country data and the literature will be presented to investigate in a systematic manner whether carbon prices can address the barriers to energy efficiency.

Barriers to energy efficiency in appliances

The market failures outlined in the previous section are evident in the appliances sector. Energy consumption by appliances can be broken down into two components: the energy efficiency of the appliance (*i.e.* the technology) and the efficiency of their use (*i.e.* the way in which the consumer operates the appliance). This subsection attempts to identify which market failures are relevant to the appliances sector and the extent of the failure in terms of potential energy savings (Step 2 in the methodology).

In the residential sector Gillingham *et al.* (2009) identified five main market failures associated with the purchase and use of energy efficient appliances:

- Externalities (energy market failures)
- Imperfect information
  - Principal agent
  - Asymmetric information
  - Lack of information

[7] IEA estimates 2010.

[8] There is a split incentive when the components manufacturer has an incentive to sell components at the lowest possible price to the final product manufacturer but no incentive to ensure that they operate efficiently once assembled.

- Behavioural failures – bounded rationality
- Liquidity constraints in capital markets
- Innovation market failures

The first three seem of most relevance to electric appliances in the residential sector. Several researchers have attempted to estimate the extent of these barriers. Murtishaw and Sathaye (2006) estimated that 25% of residential refrigerator energy in the United States, or 141 PJ and 1.3% of residential energy consumption, is affected by the principal-agent problem. The study estimates that if the principal-agent problem could be overcome 78 GWh/yr could be saved based on one year of new refrigerator sales. The same study also shows that the principal-agent problem concerns lighting but to a much lesser degree as most households can choose their own lighting and therefore it is estimated that only 2% of energy consumed by lighting is affected by this issue.

Davis (2010) examined the principal-agent problem by assessing whether tenants were more or less likely to have energy efficient appliances than home-owners. The study uses data from the United States Residential Energy Consumption Survey carried out in 2005. The energy efficient appliances include refrigerators, dishwashers, room air conditioners, and clothes washers with the ENERGY STAR label. Tenants whose utility bills are included in the rent were not part of the survey (13.4% of tenants). Statistical analysis was performed to estimate the likelihood of ownership of these appliances without controls and also controlling for household income, demographics, amount of welfare benefits, number of children, race, electricity price, and the number of heating and cooling days. In the estimation with controls it was found that homeowners were more likely by between 1% and 9.5% than tenants to own energy efficient appliances in the United States. These results are consistent with a principal-agent problem and mean that either the tenant does not purchase the appliances in a rented apartment or there is no incentive for the landlord to invest in energy efficient appliances since he/she is not paying the energy bills. Davis tests other specifications of the model to look for alternative explanations but finds that the model is robust and interprets the results as evidence of the principal-agent problem. This means that if all three of the principal-agent cases in Table 1 are considered, then the principal-agent situation arises for nearly 20% of tenants who make up 31.3% of households in the United States.

Information barriers to the purchase of energy efficient appliances abound. In many cases, there is a lack of information for consumers on the energy performance of the purchased product. The purchase of large appliances often occurs only when a previous model has broken. Therefore the purchase may be made in a hurry and purchasers do not have the time to research the energy performance of different models. In cases where the information is easily available, it may not be presented in a manner that is easily understandable. For example, the cost implications or energy savings in relation to a less efficient model may not be clear. A survey of appliance use by Japanese consumers found that very few of the respondents knew the level of energy efficiency of their appliances (Yamamoto *et al*., 2008). They were also unaware of the electricity price applied to them although more of them knew their average total electricity bill. Asymmetric information may occur where the purchaser does not have access to the same information on the energy efficiency of an appliance as its manufacturer.

Informational and energy market failures also exist in the efficient *use* of appliances. Energy market failures can be addressed through carbon pricing and higher energy prices to encourage less use or more efficient use of appliances. However, Yamamoto *et al.* (2008) show that when consumers receive only aggregated monthly electricity bills, they do not have sufficient information to optimise individual appliance use.

Behavioural economics asserts that people may make less-than-optimal decisions in the area of energy-efficient purchases and equipment use. People often choose the most satisfactory solution for them at a given moment in time rather than the optimal solution. This is a growing area of study, showing significant evidence that people do not purchase or operate their appliances in a rational manner (Yamamoto *et al.*, 2008; Simon 1997; Conlisk 1996). People often purchase and use their electrical appliances based on force of habit rather than an optimal decision-making process based on cost.

Energy efficiency policy instruments: addressing the barriers

This subsection examines whether the market failures in the appliances sector outlined previously are addressed by existing policies for the appliances sector and by carbon pricing through energy prices. The ability of first carbon/energy pricing and then the role of other policies to address mainly the first two of the market failures listed above (information failures, behavioural problems and energy market failures) is examined. Regulatory measures "should be tightly targeted to the market failure identified that is amenable to government intervention. They should meet best-practice regulatory principles, including that the benefits of any government intervention should outweigh the costs." (Australian Task Force issues paper).

This section attempts to understand the use of specific policies to address the energy efficiency of appliances in the presence of a carbon price signal in energy pricing, according to the methodology outlined in Section 2.

Policies to improve energy efficiency in appliances generally fall into one of six categories (IEA, 2009):

- **Product energy performance labelling**, such as endorsement, warning and comparison labels; information is provided to consumers on energy consumption, cost and efficiency of the product.
- **Regulatory programmes**, such as minimum energy performance standards (MEPS), energy utility obligations (demand-side management) and procurement.
- **Fiscal measures**, such as capital rebates, grants, variable consumption rates and tax credits.
- **Market-based instruments**, such as white certificate trading schemes.
- **Voluntary agreements** with appliance manufacturers.
- **Promotional activities**, such as awareness raising and information provision, awards and competitions.

A policy package involving a combination of the above instruments and **carbon/energy pricing** is often used which may be more or less effective than any of the policies implemented alone. Since the first two of these policies are by far the most common categories for policies to reduce electricity use in residential appliance, this section will focus mainly on the interaction between these two types of policies and carbon pricing.

Many researchers have pointed out the role **increasing carbon/energy prices** have played on improving energy efficiency, whether for vehicles or residential appliances. Others have demonstrated that energy efficiency policies have also driven improvements in appliance and vehicle energy efficiency, or increased the market share of high-efficiency appliances (see IEA, 2005 for examples).

Higher energy prices can address energy market failures directly and informational failures indirectly. An increase in the cost of energy could make the energy efficiency feature of a product or service more important to consumers, and spur demand for greater efficiency. People may be more willing to pay the price of obtaining better and more complete information on energy performance, should energy costs be or become a significant enough portion of overall expenses. Companies providing energy-efficiency goods and services may increase communication on these features if demand for them increases. However, they may still need a policy framework to ensure the information provided is accurate and comparable. An important impact of higher energy and carbon prices is that they can help reduce the rebound effect. As the efficiency of a product improves, consumers will be less encouraged to use the product more in response to the improvement and therefore there will be less chance of a rebound effect.

The price elasticity of energy demand is a possible indicator of how prices affect energy efficiency, which describes the reaction in energy use to a change in final energy prices. The higher the elasticity in absolute terms, the more energy users will react to changes in price; energy use generally decreases when the price increases and vice versa. The price elasticity of energy demand differs between sectors as a result of numerous factors and therefore the impact of a carbon or energy price will vary between sectors.

McKinsey's study on energy productivity found residential energy demand price elasticity to be relatively low both in the short and long-run, due to various factors including market failures that are not affected by energy and carbon prices (Table 2). Low residential price elasticity means that measures to increase the price of energy may not necessarily be effective in reducing energy demand.[9] The high price needed to achieve changes in residential energy demand would lead to challenges on other issues, *i.e.* distributive effects, economic impacts, equity issues. The study concluded that standards may be a more appropriate instrument than prices to improve energy efficiency in the residential sector.

Table 2: Residential energy demand short- and long-run price elasticity

Studies	Short-run price elasticity	Long-run price elasticity
US Bernstein/Griffin-RAND	-0.24	-0.34
Global survey Espey/Espey*	-0.28	-0.81
Beijing residential by Qi Qihui	-0.40	
Jinan China residential by Yang Lijun	-0.38	
Indian urban household	-0.29	
Australia – Akmal/Stern		-0.60
Ontario – Ryan and Wang		-0.23
New York – Dumagan and Mount		-0.07
NEMS model		-0.41

*median of ~125 estimates of price elasticity.

Source: McKinsey Global Institute, 2007.

Although certain information failures may be indirectly reduced as a result of higher energy prices, others, such as the principal-agent problem, cannot. In principal-agent relationships, the consumers faced with the energy price increase in the form of higher energy bills are not making all the decisions that could help them control their energy use. In that context, it is fully justified to consider specific policies such as standards, tailored incentives or changes to contractual relationships (IEA, 2007).

[9] The low response to price may also be explained by the low share of energy expenditures in household budgets.

In summary, increasing the cost of energy may be insufficient to overcome market failures to energy efficiency, such as imperfect and asymmetric information, or bounded rationality and transaction costs, as these prevent investment in energy efficiency even where cost-efficient under current economic conditions (Schleich, Rogge and Betz, 2009). In these instances more tailored policies to the relevant market failures are likely to be required.

Labelling programmes help overcome imperfect information by informing consumers of the level of energy consumption of an appliance and facilitating a comparison of products based on energy performance. This makes it easier for consumers to purchase products that consume less energy than required by a minimum energy performance standard and hence rewards manufacturers that sell energy efficient products. The Australian government's climate policy review found that requiring companies to disclose information to consumers is a less extreme means of overcoming information failures, as opposed to imposing energy performance standards (CoA, 2008).

Imposing **minimum energy performance standards** (MEPS) can be effective in nullifying the principal-agent problems, imperfect information and bounded rationality in relation to appliance purchase and use. In the principal-agent situation, MEPS overcome the energy efficiency gaps outlined above by ensuring a minimum energy performance even when the purchaser has no self-interest in purchasing an energy efficient product, as they do where consumers suffer from bounded rationality and do not understand energy efficiency and its significance in terms of cost to their budget and the environmental impact. MEPS help address imperfect information by reducing consumer transaction costs incurred when trying to gain information on energy performance, as consumers know that the appliances they buy will perform to a certain minimum standard. It can also be argued that MEPS do not address the individual market failures, but rather bypass these barriers to energy efficiency improvement and render them void.[10]

Regulating minimum standards and energy labelling for appliances will help improve the level of energy performance of appliances sold but will not address *how* they are used at home by the consumer; other **informational tools** are needed to provide consumers with information on the use of the appliances. A review of programmes with consumer feedback tools shows that the impact of informational tools can reduce electricity consumption in the range of 1.1% to 20% and that usual savings are between 5% and 12%, even though most of these tools do not provide information on individual appliance use (Fischer, 2008).

In this sense, combining standards with tools that help consumers use appliances more efficiently, such as smart meters and cost-reflective energy pricing, may be helpful. The UK government, for example, sees behavioural change as a separate policy target from the imposition of a carbon price, and has designed policies to complement each other in addressing both behavioural failure and the lack of a carbon price (Pourarkin, 2010).

From this discussion it appears that not all market failures acting as barriers to optimal energy efficiency in the appliances sector can be addressed by carbon and energy pricing. In particular, market failures such as principal-agent problems relating to asymmetric information and split incentives, behavioural failures (such as bounded rationality), and transaction costs can be better addressed by appliance MEPS, labelling, and other informational tools. Since these policies have fulfilled the criterion that they do address a market failure relating to energy efficient appliances, they are carried forward to the next subsections on effectiveness, efficiency and interaction with carbon pricing.

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[10] We are grateful to Hans-Paul Siderius for his comments here.

Effectiveness and efficiency of appliance energy efficiency policies

Significant evidence shows that appliance MEPS and labelling programmes have generally been successful in terms of their effectiveness in saving energy and cost efficiency. The IEA Implementing agreement 4E operates a mapping and benchmarking programme in appliances energy efficiency. There is significant evidence to show that countries with MEPS have lower energy-consuming appliances.[11]

Schiellerup (2002) investigated the effect of MEPS for cold appliances in the United Kingdom. The study estimated that 3 TWh was saved over the lifetime of products bought after the standard went into the effect, compared to products bought had there been no standard in place. The UK cold appliances market was transformed by the standard; immediately following its coming into effect, the average energy consumption of most product groups dropped more rapidly than the historical trend.

Meyers, McMahon and Anderson (2008) estimated the energy, environmental and consumer economic impacts of US federal residential energy efficiency standards (MEPS) from 1988 to 2006, drawing on existing analyses conducted by the US Department of Energy (DOE) as part of its standards rulemaking process. They estimate that standards will have reduced residential sector primary energy consumption and associated CO_2 emissions by 8% in 2030.

An analysis of the potential impact of an international appliance MEPS and labelling programmes in six major economies finds that total electricity savings from such an initiative could reach 1 301 TWh in 2030 (McNeil *et al.*, 2009). *Cool Appliances* (IEA, 2003) shows evidence of the energy savings achieved by standards and labelling programmes in IEA countries over the past decades. For example, it is estimated that energy labelling of appliances in Australia in 1986 meant that annual energy consumption of al new appliances sold in 1992 would have been 11% higher. In the European Union an evaluation of the sales-weighted average energy-efficiency index of refrigerators and freezers fell 22.4% from 1990/1992 to 1999, as a result of labelling programmes (Waide, 2001). Natural Resources Canada also estimated that appliance standards have caused a reduction in energy use of between 18% and 45% for refrigerators, freezers, dishwashers, washing machines and dryers (NRCan, 2001).

In an assessment of major energy efficiency policies in the United States, Gillingham, Newell and Palmer (2004) estimated that the cost-effectiveness of efficiency standards for residential appliances was approximately USD 3.3 billion/quadrillion British thermal Units (BTU) saved in 2000, which translated into USD 0.038/kWh, whereas the average price of electricity was USD 0.074/kWh. This could translate to a benefit of USD 61 per tonne CO_2 emissions reduced.[12] They conclude that MEPS are likely to have positive net benefits, which could be augmented by up to 10% if the value of reducing air pollutants associated with avoided energy consumption is taken into account.

McKinsey's global marginal abatement cost curve (MACC) places efficient lighting systems and air conditioning as measures that achieve GHG emission reductions at zero or negative cost (between -60 EUR/tCO_2 and -80 EUR/tCO_2), *i.e.* at no net cost to the economy.[13] In MACC analysis developed by McKinsey for Germany, the UK, Australia and the United States, residential appliance, equipment and lighting efficiency improvements are negative cost measures across the four countries, though the specific cost varies (AP Envecon, 2009). The GAINS EU27 MACC

[11] Available at http://mappingandbenchmarking.iea-4e.org/

[12] Based on average US emissions factor 586 gCO_2/kWh from fuel combustion in 2000 (IEA, 2010c).

[13] A marginal abatement cost curve is a graph illustrating the marginal costs (*i.e.* the costs per last tonne of abatement) of different options to abate pollution (in this case GHG emissions) in order of rising abatement costs.

also places such measures in the negative range of the cost curve for the EU 27, with domestic appliance efficiency improvements and both commercial and residential lighting improvements in the range of -180 EUR/tCO_2 to -200 EUR/tCO_2.

The Meyers *et al.* (2009) study estimated that the cumulative net present value of consumer benefits over time as a result of the United States energy efficiency appliance MEPS would reach USD 241 billion by 2030. The overall consumer benefits to costs ratio was estimated at 2.7 to 1 for the 1987-2050 period. This shows that appliances MEPS and labelling policy programmes have led to energy savings at below cost in most cases in the literature.

Interaction between appliance energy efficiency policies and carbon pricing

Clearly, appliance MEPS and labelling policies can address market failures not addressed by carbon pricing in a cost efficient manner. The next step is to investigate whether these policies interact with carbon pricing.

With the goal of generalising the potential impact of policy interactions in the appliances sector, it is less useful to carry out assessments using data on individual policies. Therefore an approach more similar to that used by Boonekamp (2006) is applied here.

Table 3 presents a simple matrix of the main market failures causing sup-optimal energy efficiency in the appliances sector and the main policies applied. The ability of the policy to address the market failure is indicated with H (high impact), M (medium), L (low) and – (no impact). From this simple overview it would appear that the only market failure impacted by both carbon pricing and the energy efficiency policies – MEPS and information – is information failure and even there, carbon pricing is considered to have only a low impact on this market failure. In the other cases of market failure, carbon pricing, MEPs or information can have a high impact but do not impact the same market failures and therefore it appears that MEPs and information are complementary policies to carbon pricing. There appears to be more possibility of overlap between the two energy efficiency policies, MEPS and information, than between carbon pricing and MEPS and information. The next paragraphs inspect the detailed impacts of these policies to see whether there is a problem with the overlap of energy efficiency policies.

Table 3: Matrix of energy efficiency market failure targets and policies for appliance electricity use

Market failures→ Policies↓	Energy market failures: - Negative externalities	Principal-agent problems: - Split incentives - Asymmetric information	Informational failures: - Insufficient performance information available to decision-maker - Information difficult to understand - Energy price aggregated	Behavioural failures: - Bounded rationality
Carbon pricing	H	-	L	-
Minimum energy performance standards	-	H	H	H
Information: - Labelling - Informational tools	-	L	H	M

As discussed earlier, there are two different kinds of energy efficiency actions in the appliances sector – (i) the purchase of energy efficient appliances, and (ii) the efficient use of appliances. On the first of these, MEPS and labelling have different roles to play. Information failures can be overcome by MEPS: as all appliances on the market must meet a MEPS, appliance purchasers will no longer need information on energy efficiency in order to purchase an appliance reaching a level of minimum energy performance.[14] MEPS can also overcome the split-incentive problem: regardless of whether the purchaser will reap the benefit of the energy savings, she is forced to buy an appliance that at least meets a minimum performance standard. Similarly they overcome consumer bounded rationality. In this respect, appliances MEPS meet one of Boonekamp's criteria in that they address multiple market failures.

An energy label on an appliance addresses some of the same market failures as MEPS but with a different result. Labelling also overcomes information failures but can encourage the purchase of event more energy-efficient appliances by enabling the consumer to choose between products above a MEPS. This encourages manufacturers to supply appliances that exceed the MEPS, as this fact is communicated through the label to the potential purchaser. This avoids the trap of MEPS that encourage only minimum efforts on the part of manufacturers. The principal-agent problem addressed by energy labelling is not split incentives but rather asymmetric information. Although information failures and principal-agent problems relating to energy-efficient appliance purchase are addressed by both standards and labelling, the impacts are different, leading the conclusion that in this issue the two policies are complementary.

Regarding the market failures relating to the efficient use of appliances, there is less potential for overlap between energy efficiency policies. As we have seen in the previous section on policies to overcome market failures to energy-efficient appliances, carbon pricing and informational tools have the highest impact of the energy-efficient use of appliances. These policies address different market failures: whereas carbon pricing addresses energy market failures due to climate change externalities, informational tools address information failures. Informational tools such as electricity feedback tools, *e.g.* smart meters, can provide consumers with much more detailed and immediate information on their electricity consumption and on varying prices according to the time of day. Feedback information can make carbon pricing more visible, and therefore allow it to have a greater impact. It can be considered a policy enabler in this respect.

In their study of room air conditioners and gas heaters in the United States, Newell, Jaffe and Stavins (1998) found that energy price changes, along with autonomous improvement[15] and MEPS, led to energy efficiency improvement. They also found that the responsiveness of energy-efficiency innovation to energy prices increased *after* energy-efficiency labelling requirements for these appliances took effect. Better information can thus facilitate energy efficiency improvements, and policies to increase information can enhance the effectiveness of price signals.

Energy efficiency policies such as MEPS and labelling can be more effective in combination with a carbon price. Consumers may be more aware of energy consumption as a result of a carbon price, as a signal of an environmental problem, and therefore take the time to understand an energy performance label when purchasing an appliance. Once purchased, a carbon price can complement the MEPS and label by motivating more energy-efficient use of the appliance, reducing the rebound effect. The rebound effect can be minimised if the carbon price is set so

[14] Of course, if the purchaser would like to purchase an appliance with better energy performance than the MEPS then information is required to make that choice.

[15] Autonomous energy efficiency improvement is the improvement in energy efficiency due to ongoing technological advancement that occurs year-on-year even in the absence of policies and is estimated to be 1-2% annually (IEA, 2005).

that any monetary gains from the energy savings are offset by higher energy prices which diminish the motivation for higher use of the appliance.[16]

The Australian government's Task Group on Energy Efficiency highlights the need for a carbon price to dramatically improve the country's energy efficiency, but pointed to continued MEPS and labels as a policy area that is both low-cost and will not compromise later policy decisions (CoA, 2010). In its examination of complementary policies needed in the presence of an economy-wide carbon price, the Australian government's strategic review of climate change programmes recommended that the government continue to have a role in setting and disclosing performance standards for energy use in appliances (CoA, 2008). The review also concluded that while putting a price on carbon was expected to shift the technology supply curve, this would take time; meanwhile, consumers would likely be reticent to buy more efficient technology without other policies designed to encourage energy efficiency.

In summary, it appears that carbon pricing does not nullify the need for appliance energy performance standards and labelling to improve energy efficiency at least cost. In fact these can serve to positively reinforce carbon and energy pricing.

[16] Many thanks to Hans-Paul Siderius for this point.

Heating energy use in the buildings sector

This section focuses on heating energy use in buildings. It discusses the extent of market failures as barriers to energy efficiency in this subsector and how policies address these barriers and interact with carbon pricing (steps two and three in the methodology).

Space and water heating represents a large share of total end-use of energy in commercial and residential buildings. The single largest use of energy in residential buildings in the United States, European Union and China is for space heating, followed by water heating (IPCC, 2007). Space heating is also the single largest use of energy in commercial buildings in the European Union, accounting for up to two-thirds of the total energy use, as well as in the cold regions of China and Russia.

There are several key features that distinguish the energy use for heating services from electricity consumption in appliances. The energy use for space heating is determined by technical aspects, such as the building envelope (its size, orientation, insulation features), the quality of design and construction, and the energy performance of heating equipment, as well as behavioural aspects of the occupants (*e.g.* the desired level of comfort, consumption patterns, maintenance). In addition, heating could be delivered by various energy sources (electricity, oil or gas) that have different prices and may be affected differently by carbon pricing.

Barriers to energy efficiency in space and water heating in buildings

There is a significant economic and technological potential for energy efficiency improvements in the building sector. Studies in Switzerland indicate that for all buildings constructed before 1976 the heat demand can be profitably reduced by half at 2005 fuel oil prices, *i.e.* at around USD 67 per 100 litres (Amstalden, R., M. *et al.* 2007). However, the profitability of measures does not always translate into the reality of actually taking these actions due to the persistence of barriers to energy efficiency.

The following energy efficiency market barriers have been identified by scholars, professionals and policy-makers in the building sector (*e.g.* Amstalden, R. M. *et al.*, 2007):

- Imperfect information
- Principal-agent problems
  - Asymmetric information
- Behavioural failures
  - Bounded rationality
- Organisational failures

These replicate those found for appliances with the addition of organisational failures, which are specific to the buildings sector and are mainly caused by fragmentation of the sector.

It is useful to examine market failures impacting energy efficiency in existing and new buildings separately, as the opportunities and constraints related to energy efficiency are different in these two segments of the building sector. The actual performance of a new building will depend primarily on the quality of construction, design, and the energy performance of the envelope and building components. For example, a new building can be highly efficient where an integrated design process includes selecting a high performance envelope and highly efficient, properly sized equipment, as well as incorporating a building energy management system that optimises the equipment operation and human behaviour.[17] In an existing building, efficiency can be maintained or improved through maintenance, retrofits (more efficient heating and cooling systems and insulation), and changing consumption patterns.

Existing buildings

Lack of information is often given as a reason why consumers systematically under-invest in energy efficiency. Consumers lack information about the difference in future operating costs between more efficient and less efficient goods that is necessary to make proper investment decisions (Gillingham *et al.*, 2009). One Swedish study found that owners of multi-dwelling buildings are more likely to invest in energy efficiency measures than single home owners. The study explained this finding by the assumption that owners of multi-dwelling buildings acting as a group are better able to gain energy efficiency knowledge (*e.g.* by hiring experts), while single owners may have to gather and synthesise information from many different sources to find the most cost-effective investment, which may entail substantial transaction cost (Nassen *et al.*, 2007).

Principal-agent problems can be prevalent in existing buildings – particularly in the rental building sector. Murtishaw and Sathaye (2006) attempted to quantify the magnitude of this problem for four end uses in the United States: space heating, refrigerators, water heating and lighting. They found that the principal-agent problem is potentially relevant to 77% of water heating energy use, 48% of space heating energy use, and is negligible (2%) for lighting energy use. Other evidence shows that homeowners have lower heating bills than tenants since they can invest in energy efficiency measures such as insulation (Gillingham *et al.* 2010).

A **split incentive** arises when energy bills are included in the monthly rent and tenants do not pay for heating. More than one quarter of rental apartments in the United States include the cost of utilities in their rent. Tenants in this situation have no price incentive to conserve energy, and, therefore, use more energy than tenants in individually metered apartments (Gillingham *et al.* 2010). In such cases landlords may, however, invest in energy efficient equipment that will reduce the energy consumption of the tenants and their own energy bills.

If utilities are not included in monthly rents, the classic principal-agent problem occurs where landlords have little incentive to invest in energy-efficient construction, appliances or insulation. So although tenants (who pay the energy bills) have an incentive to consume less energy, landlords are not interested in investing in more energy efficient equipment. Studies comparing these two different rental billing models have found that the heating energy use in utility-included apartments is less than in apartments where the rent does not include utilities (Levinson *et al.,* 2004, Gillingham *et al.,* 2010). It seems that investment in energy efficient equipment has a stronger impact on energy use than energy efficient behaviour, or in other words the split-incentive issue is more significant for heating energy demand than the principal-agent problem.

In the case of split incentives, the impact of carbon pricing is limited since a price signal can only be effective if it reaches the relevant energy consumer. In Sweden, where 99% of tenants in multi-dwelling buildings do not pay individual energy bills, the short-run price elasticity (or how responsive demand for energy is to a change in its price) was found to be significantly lower in

[17] The integrated design process can usually achieve energy savings in the order of 35-50% for a new commercial building, compared to the standard practice, while utilization of more advanced or less conventional approaches has often achieved savings in the order of 50-80% (Harvey, 2006).

such buildings (with more tenants) than in one- and two-dwelling buildings (with more home-owners) (Nässen, Sprei and Holmberg, 2008).

An example of **asymmetric failure** in property purchases is when property market prices do not reflect the energy performance of a building or this information is not available to a potential buyer. It is therefore difficult for a building owner to recoup the cost of the energy efficiency investment when they sell a property, even if the payback period is short.

As mentioned in Section 3, **behavioural failures** such as bounded rationality also compound market failures, as does a lack of initial capital for energy efficiency investments. These can lead to situations where the availability of cost-saving energy efficiency measures will not be exploited, either because of limitations in consumer capacity to exploit information, "irrational" economic behaviour, or various financial barriers.[18]

New buildings

For both commercial and residential buildings, the cost of achieving a better energy performance will usually be lower in new buildings than in existing buildings, and the achievable energy performance is much better for new buildings. However, market failures for energy efficiency actions in new buildings are even stronger than in existing ones.

Information failures are one of the energy efficiency market failures affecting new buildings. The life-cycle cost (LCC) of new buildings appears not to be known by households and clients. For example, when examining stagnation in building energy efficiency levels, Swedish researchers found that the correlation between energy prices and specific energy use for heating seen in existing buildings was weak in new buildings. An important cause of this was that information about the life-cycle cost of different investments in new buildings affecting energy use was often not available to building sector actors (Nässen, Sprei and Holmberg, 2008). A client's focus, when planning a new building, is to minimise up-front investment costs, rather than the LCC, which would take account of current or expected future energy prices. Moreover buildings standards tend to be the default minimum level of energy performance, even if it may be cost-effective to build to a higher standard.

Asymmetric information can lead to the problem of **split incentives** in the construction of buildings. For example, building contractors in general may have no incentive to consider or provide information on energy efficiency options, even where these would be more economically sensible for their clients (Atkinson, Jackson and Mullings-Smith, 2009).

Principal-agent problems can also arise at the time of construction, as evidenced in the way typical design and build contracts are set up. One UK study found that many phases of building construction are implemented through subcontractors chosen based on competitive bids, where the cost is the selection criterion. Companies try to minimise cost at the expense of building design. Building services engineers usually come at the last step when it is too late to make changes in building orientation, form, layout and electrical load (Sorrell, 2003).

In addition, the **fragmentation** of the construction industry reinforces these market failures through various organisational barriers. This industry is characterised by a large number of small-scale builders. The proportion of firms in this sector employing fewer than 10 persons was 81% in the United States, 93% in European Union countries and 75% in Japan (OECD, 2003). Small firms generally do not have specialised staff for research and development, and are slow to adapt to new technologies. Small firms can only take care of some components of new construction and

[18] For more on financial barriers related to residential energy efficiency investments, see De T'Serclaes (2007) and IEA, 2008.

do not have the capacity to handle the whole construction process in an integrated manner. Thus, construction projects require the involvement of a large number of actors: clients, architects, lawyers, consultants, equipment suppliers, construction workers, building commissioners, etc. The complex interaction between different actors/organisations in constructing a new building creates barriers to energy efficiency since the fragmentation prevents a strategic approach to optimising energy efficiency of a new building.

Energy efficiency policy instruments: addressing the barriers

This section first discusses the low energy price elasticity in the buildings sector and illustrates the need for additional energy efficiency policies even when externalities are included in energy prices. It then analyses the interaction of specific energy efficiency policies with carbon prices.

Lessons learned on price elasticity

In theory, high energy prices facilitate energy efficiency investments that lead to reduced consumption of energy. However, evidence suggests only a weak correlation between energy prices and investments in energy efficiency in buildings. The analyses conducted by researchers in many countries demonstrate relatively low energy price elasticity in the buildings sector, with some variations by country and region. For example, a model simulation conducted in the Netherlands showed that a 20% increase in energy prices provoked some energy saving measures by households. However, a price increase of 20% to 100% changed did not change these savings substantially. It is possible that there is a threshold for a technical solution and then above that level little improvement can be made until a further cost threshold is broken. The Dutch study suggests that besides various other barriers to energy efficiency (discussed earlier in this section), the lack of energy saving options may have prevented higher price elasticity (Boonekamp, 2007). Thus, it is not clear whether the barrier is a market one, or simply the lack of technical solutions beyond a certain threshold of energy savings. More empirical evidence is needed to investigate this issue.

In Sweden, on the contrary, it was observed that specific energy use for heating in existing buildings had a high correlation with increasing energy prices, and that price elasticity had not changed markedly over time. However this correlation was much weaker in new buildings and in general, a change in specific energy use required a relatively important increase in energy prices (Nassen, J. *et al.*, 2008). In fact a 30% reduction of energy use – the goal of the voluntary agreement between government and buildings sector in Sweden – would correspond approximately to a three-fold increase of energy prices which is unlikely to be feasible politically if the price elasticity remained at its current level. Another study analysed the effects of prices and income on energy consumption and concluded that people adjust their energy use much slower in reaction to changes in energy price than to changes in their income in virtually all countries (Gately *et al.*, 2001).

The findings suggest that the range of energy price fluctuations observed in the last decade will have only a limited effect on energy efficiency uptake in the buildings sector. In addition, given that a common energy policy goal is to offer society affordable energy services, any future price-induced reduction of demand can be expected to be relatively small. In this case, a substantial set of policy measures to enhance energy efficiency will be needed to realise demand reduction in line with energy saving goals.

Effectiveness and efficiency of buildings energy efficiency policies

Various energy efficiency policies have been used by governments to address energy efficiency barriers. Unfortunately, it is hard to find estimates of the cost and GHG reduction benefits from these policies individually or information on which barrier each policy was designed to address. Policies are usually developed in packages and reinforce each other as well as the price signal. In addition, these policy packages commonly address several barriers simultaneously.

The following policy instruments have been used by governments to promote energy efficiency and address energy efficiency barriers:

- **Buildings and equipment standards**;
- **Labelling and information programmes**;
- **Fiscal policies**, including tax credits, loans and subsidies; and
- **Coordination** of various actors involved in a new construction.

Buildings and equipment standards are a key instrument influencing energy efficiency performance of building systems. Standards set a minimum level of energy efficiency that products must meet. According to the analysis conducted by the Wuppertal Institute (Bleischwitz *et al.*, 2009), building standards are the preferred policy option in the European Union to address barriers to energy efficiency. For example, the European Union Energy Efficiency of Hot-water Boilers Directive (1992/42/EEC) applies minimum energy efficiency standards to hot-water boilers fired by liquid or gaseous fuel.

A Hungarian study shows that under an aggressive scenario of stringent energy efficiency buildings standards, public buildings in Hungary can reduce energy consumption by 23% compared to business as usual in 2030, with a 73% reduction in CO_2 emissions at a negative cost.[19] The study concludes that the retrofit rate of existing buildings is not the most important factor in determining energy saving potential. More important is the level of performance to which the buildings are retrofitted (Korytarova and Urge-Vorsatz, 2010).

Standards ensure that the desirable energy performance of building components and heating equipment is achieved even when its purchaser does not show interest in obtaining more efficient products due to either behavioural failure or lack of incentives. Standards also put a burden of reaching a desirable energy performance level on producers of equipment, and not on users who may experience barriers in obtaining information that would guide them to more efficient equipment. Standards also allow the market expansion of efficient equipment without customers being personally involved in making rational decisions about purchasing such equipment (thereby addressing the problem of bounded rationality).

In addition, standards (*e.g.* the Swiss "Minergie" label and the German passive house standard) have an innovation-stimulating effect on producers, building owners and architects, serve as benchmarks and result in market transparency.

Labelling and other information programmes aim at introducing energy efficiency investments by overcoming informational failures, and informing consumers about energy costs and potential energy savings. The Building Research Establishment Environmental Assessment Method (BREEAM), a voluntary environmental labelling scheme for buildings, was established in the United Kingdom in 1991 and covers new and existing office buildings, supermarkets, schools and houses. It has had an important impact on reduced energy use and associated CO_2 emission

[19] Total cumulative investments between 2011 and 2030 would be EUR 2.62 billion, while the cumulative energy cost savings would be EUR 3.24 billion.

reductions. The ex-post analysis of the programme's effectiveness found that BREEAM-assessed buildings emit 60% less CO_2 per year than typical buildings (OECD, 2003).

Empirical evidence supports the argument that information has significant influence on household decision-making in energy efficiency improvements. Consumer feedback programmes (that provide consumers with real-time information about their energy (mainly electricity) consumption) induce energy conservation with typical savings of 5% to 12% (Fischer, 2008). An evaluation of energy audit programmes in the United States showed that energy audits had influenced the decision-making of approximately 67% to 80% of the households participating in the programme.[20] A similar study in Denmark found that households that receive energy reports implemented 17% more heating-related upgrades than households without such reports (OECD, 2003).

The US ENERGY STAR programme offers information to prospective homebuyers about the features and benefits of energy saving devices. It also offers free information to help builders understand energy efficiency opportunities. The analysis of the US ENERGY STAR programme shows that the certified homes are at least 15% more energy-efficient than homes built to the 2004 International Residential Code (IRC). In 2009, families living in one million ENERGY STAR-certified homes saved more than USD 270 million on their utility bills, while avoiding greenhouse gas emissions equivalent to that of 370 000 vehicles per year (www.energystar.gov).

Access to capital barriers are often addressed by **fiscal policies**, including favourable loans, tax breaks and subsidies. Fiscal policies aim at reducing capital costs to make energy-efficient investments more attractive. Many governments provide funds to facilitate access to capital and encourage energy saving measures. Germany's government-owned Bank for Reconstruction (*Kreditanstalt für Wiederaufbau*, KfW) provides financing (EUR 1.5 billion in 2009) in low-interest loans and grants for innovative energy efficiency investments in residential buildings and local infrastructure.

Tax incentives are another relevant fiscal policy measure. For example, Japan's 2007 Budget Law includes funding of EUR 15 million for two years to underwrite a provision allowing a tax deduction for the implementation of projects to enhance energy efficiency in buildings. Under the US ENERGY STAR programme, households purchasing an energy-efficient product or a renewable energy system for their homes may qualify for a federal tax credit of up to USD 500 or 10% of eligible costs of energy-efficient equipment.

Some of these programmes focus on the low income population and other vulnerable social groups. For example, the UK government announced USD 80 (GBP 50) million of investment in the Warm Front programme in 2009-10, which supplies insulation and heating measures to vulnerable households.

Addressing contractual issues of new and existing buildings construction could alleviate some key barriers to energy efficiency in new buildings. The literature suggests that new construction offers large and cost-effective opportunities for energy efficiency improvements and associated emission reductions. However, the examined literature provides only a few examples of policy packages designed to address the barriers to energy efficiency caused by the complexities of the construction industry. In one example in the United Kingdom, low interest rates for capital borrowing coupled with longer repayment periods improved the economic case for low-carbon design (Atkinson, J.G.B. *et al.*, 2009).

[20] In one U.S. state, participants in a Residential Conservation Services programme realised 32% of the identified potential savings for space heating compared to 12% for non-participants.

Policy measures are often used in combination, and interact with various price signals. Analysis shows how three policy measures – standards for new dwellings, subsidies for more energy efficient systems and equipment, and a regulatory energy tax – along with changing energy prices affected energy-saving behaviour. The analysis concluded that price elasticity for gas and electricity was 25% to 30% lower in the presence of all three policy measures than in their absence. This is explained by the fact that energy saving measures would be taken mostly as a result of these policies and not as a result of the change in energy prices. However, the combination of three policy measures yielded 13% to 30% less effect than the sum of the effects of the individual policies, indicating the potential for overlap of policies. The authors suggested that the most important way for prices to influence energy consumption was via the choice for more energy efficient new systems or appliances, at least in the Netherlands and over a longer time frame (Boonekamp, 2007).

Another study conducted in Switzerland analysed the effect of policy instruments such as subsidies, income tax deduction and carbon tax on investment decisions. The study showed that all instruments had a significant effect on the net present value, although no policy instrument alone could make energy-efficiency measures profitable. Yet, the combination of all policy instruments makes even the most advanced retrofit package profitable. The effect of carbon tax was found to be about half of that of income tax deduction or subsidies (Amstalden *et al.*, 2007).

Interaction between building energy efficiency policies and carbon pricing

Table 4 presents a simple matrix of the main market failures causing sub-optimal energy efficiency in the space and water heating sector and the main policies to address them. The ability of the policy to address the market failure is indicated with H (high impact), M (medium), L (low) and – (no impact). Similar to energy efficiency policies in the appliances sector, heating-related energy efficiency policies also appear to be generally complementary to carbon pricing.

Table 4: Matrix of market failure targets and policies in buildings heating energy use

Market failures → Policies↓	Negative externalities	Principal-agent	Information failure	Behavioural failure
Carbon Pricing	H	-	L	L
Building standards	-	H	H	H
Labelling, information programmes	-	M	H	M
Fiscal policies: subsidies, tax rebates	M	-	-	M
Contractual measures for new constructions	L	H	M	H

Buildings standards set a minimum energy performance that overcomes problems with inherent information failures and principal-agent problems, as well as behavioural limitations, in terms of buildings design, construction and installed components. Regardless of how a building contract is established, standards will address these issues by ensuring a certain level of technically and economically achievable energy efficiency is met. While this is most effective in targeting new buildings, standards can also have an impact on existing buildings as they can apply to major renovations. In addition, energy performance standards for building components (such as windows) and heating equipment (such as boilers) will also address market failures that negatively affect energy-efficient choices when such products are replaced.

Labels also address the same market failures, but in a different way. For components and heating equipment, they allow consumers to choose products with an energy performance level above the minimum standard. Similarly, building energy performance labels or certificates will provide information on aspects of the building's energy performance that are not visible and are not necessarily under the control of its future owner or tenant. This is particularly important in the rental sector where tenants are responsible for energy bills, as it allows for comparison and can facilitate the selection of a more energy-efficient dwelling. Other information tools also have an impact on behaviour and how energy is used. Building audits and feedback tools, such as better metering, make energy use and associate costs more visible, and enhance the appeal of energy-efficient renovations or replacement of inefficient heating equipment. While higher energy prices may also stimulate behavioural change, their impact may be limited due to low price elasticity. Information tools help consumers make more informed decisions when faced with a higher energy price, as they enable consumers to target energy efficiency measures to reap greater cost savings.

Fiscal incentives should, strictly speaking, be applied only when positive external effects of energy efficiency are identified that the market cannot address. Although a carbon price should already manage this, the use of subsidies and other fiscal incentives can have an additional impact on behavioural failures. Notable, they do so in a complementary way; as a policy option, such incentives generally need to be aligned with labelling schemes and voluntary standards to be effective (IEA, 2008). Tax rebates, low-interest loans and other incentives for efficient components and heating equipment are generally based on performance levels higher than minimum standards, and are linked to energy performance categories communicated through labels and other comparative information tools. It is likely that fiscal instruments have the most potential of the common energy efficiency policies to overlap or duplicate carbon pricing, and will need further investigation to determine the extent of this.

This reflects a Dutch study that found that subsidies and high energy prices decrease the cost/benefit ratio and thereby increase efficiency. However, the study also concluded that while subsidies increased the effectiveness of a price increase in some cases, in others the opposite was true or there was no effect (Boonekamp, 2007). More investigation is needed to determine the effects of fiscal incentives on actions to improve energy efficiency.

Current UK energy policy includes many different forms of market persuasion to encourage better energy performance in buildings. Buildings regulations are combined with fiscal measures such as taxation on fuel and power demand (Climate Change Levy and VAT), as well as capital grants available for different economic sectors through the Low Carbon Buildings programme to promote new technologies. This UK example illustrates the need for a policy package to stimulate investments in energy efficiency and alter energy consumption behaviour in the building sector.

These findings point to the conclusion that current policies are not enough to catalyse a shift toward energy-efficient technologies in buildings but that a set of policies addressing both market and behavioural failures potentially generates a more efficient overall response. Ensuring a price that accurately reflects the cost to society of energy use may be insufficient to reduce actual energy consumption and stimulate investment in more energy efficiency; such a price may not address known market failures that prevent the uptake of energy efficiency. Complementary policies interact in a positive way with carbon pricing and reinforce the price signal.

Conclusions

The main message of this paper is that while carbon pricing is a prerequisite for least-cost carbon mitigation strategies, it is not enough to overcome all the barriers to cost-effective energy efficiency actions.

Starting from an inventory of existing market failures that attempt to explain the limited uptake of energy efficiency, this paper explored which of these can be overcome by carbon pricing in residential appliances electricity use and buildings heating energy use.

We found that carbon pricing mainly addresses energy efficiency market failures such as externalities. However, we identify several market and behavioural failures in appliance electricity use and building heating energy use that appear not to be addressed by carbon pricing. These include:

- Informational failures
- Principal-agent problems
- Behavioural failures.

We consider that policies that address these market failures are complementary to carbon pricing and should be implemented when they can improve energy efficiency effectively and efficiently (and achieve other national goals such as improving national socioeconomic efficiency). Examples of policies to address market failures in appliances electricity use and buildings heating energy use are provided in Table 5. These energy efficiency policies address both end-users' investment and end-use behaviour. They also direct suppliers of equipment towards the production and sale of more efficient products as they enhance their market value to consumers – a market-transformation effect.

Table 5: Energy efficiency policies and market failures in energy use in electric appliances and building heat demand

Market failures	Appliances electricity use	Building heating energy use
Informational failures	Energy labelling Consumer feedback tools Awareness raising measures Minimum energy performance standards	Building energy performance standards Energy performance certificates Energy audits and other consumer feedback programmes
Principal-agent problems **• Asymmetric information** **• Split incentives**	Energy labelling Minimum energy performance standards	Building standards Energy performance certificates Targeted contractual measures for new construction
Behavioural failures **• Bounded rationality**	Minimum energy performance standards	Building standards Energy performance certificates Targeted contractual measures for new construction Fiscal measures

From a socio-economic efficiency perspective the most important policy lessons for the energy efficiency field is to employ (and enhance) the market's ability to signal economic scarcities and combine this with different informative policy instruments. This would improve market actors' ability to undertake efficient choices. Various regulations (*e.g.* building codes, product standards, etc.) and information measures are necessary when they can address important market and behavioural failures in energy use.

There is much evidence, some of which is referenced in this paper, about the net economic life-cycle benefit of many measures promoting energy efficiency. These economic benefits would only be enhanced by a price on CO_2 emissions reflected in final energy prices. For some of the more expensive measures, further analysis would be needed to evaluate whether the cost of mobilising energy savings is worthwhile from public policy perspective. Governments should conduct complete cost-benefit assessments with clear identification of the policy priority goal (carbon emission reduction, socio-economic efficiency, security of energy supply) to guide their "investment" in new policy tools.

Next steps

This paper has illustrated the need for energy efficiency policies to complement carbon pricing, with an aim to achieve CO_2 emission reductions at least cost in the energy sector. The findings will feed into the IEA work *Combining Policy Instruments for Least-Cost Climate Mitigation Strategies*, where it will be combined with analysis of the interaction with support measures to low-CO_2 supply technologies such as renewables.

Future work should extend this investigation to other sectors and energy efficiency policy instruments. In particular, more analysis is needed of the interaction of energy efficiency market-based instruments with carbon pricing, where there is likely to be more overlap. In future work, it is also important to examine the different impacts of emissions trading schemes and carbon taxes in their interaction with energy efficiency policies. The impact of the level of the carbon price on energy efficiency policy should also be explored. For example, evidence suggests that in the sectors covered by the EU emissions trading scheme, the effectiveness of energy efficiency measures on emissions may be diluted.

Further work is also needed into how to better design energy efficiency policy in tandem with carbon pricing to minimise the rebound effect.

Evidence should be collected from countries with several years of experience in using market-based and fiscal instruments in energy efficiency policy. Modelling of the potential interactions between these instruments with carbon pricing should be helpful in identifying the conditions where positive and negative impacts can be expected.

This future work should culminate with detailed proposals on the design of energy efficiency policies that positively interact with carbon pricing and other climate policies.

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