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SYNTHESIS

Running heat: Transaction costs analysis of LCTs

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Transaction costs analysis of low-carbon technologies

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Abstract

Transaction costs (TCs) must be taken into account when assessing the performance of policy instruments that create markets for the diffusion and commercialization of low-carbon technologies (LCTs). However, there are no comprehensive studies on the development and application of transaction cost analysis to LCTs. In this meta-analysis, a wide-ranging evaluation of TCs associated with energy efficiency, renewable energy, and carbon market technologies is provided. There is a plethora of different definitions of, and measurement techniques to estimate, TCs. There is wide variation in the quantitative estimates, which can be attributed to factors such as the definition used, data collection, quantification methods, the type and size of technologies, the regulatory frameworks, the complexity of transactions, and the maturity of policy instruments. It is concluded that TCs are highly specific to both LCTs and policy instruments and thata common methodological approach is needed to avoid misleading policy analysis of the extant and future assessments.

Policy Relevance

Transaction costs (TCs) accrued by, for instance, the search for information, due diligence, monitoring and verification (M&V) activities, must be considered in the design, implementation and assessment of policy instruments. Such costs can have a negative effect on the performance of policy instruments aimed at the diffusion and commercialization of low-carbon technologies. It is shown here that TC analysis is mostly technology and policy context-specific and hence that it is not advisable to make generalizations about sources and estimates. The nature and scale of TCs are likely to differ due to a variety of endogenous determinants (e.g. size and performance of technologies), exogenous drivers (e.g. regulatory policy frameworks), and methodological aspects (e.g. quantification techniques). Several measures and strategies have the potential to reduce TCs, including standardized full cost accounting systems, an *ex ante* M&V approach, project bundling, and streamlining of procedures.

Keywords: carbon markets; energy efficiency; GHG emissions; low-carbon technologies; renewable energy; transaction costs

1. Introduction

Transaction costs (TCs) can have a detrimental effect on the diffusion and commercialization of low-carbon technologies (LCTs) and, consequently, the potential for carbon emissions reductions (IPCC, 2007; Sonntag-O'Brien & Usher, 2004). Those associated with LCTs can reduce the performance of energy and climate policy instruments in terms of their economic efficiency, cost-effectiveness, and environmental effectiveness (Stavins, 1995; Mitchell et al., 2011). They are an important factor in public policy; ignoring them risks generating biases in policy design and instrument choice (Tietenberg, 2006) and lessens the impact or validity of policy evaluations (McCann, Colby, William Easter, Kasterine, & Kuperan, 2005). Although there are several theoretical studies of TCs and general environmental policy (e.g. Fullerton, 2001; Stavins, 1995; Montero, 1998) they have been less frequently addressed in empirical policy evaluations (IPCC, 2007; McCann et al., 2005; OECD, 2002).

Transaction costs can be broadly defined as costs that are not directly involved in the production of goods or services but which arise from transactions or contracting activities that are essential for the trade of such goods and services (Coase, 1960). The economic benefits of reducing GHG emissions via LCTs may be outweighed by, for instance, the costs of searching for and assessing technical information, those associated with negotiations, those related to regulatory uncertainty, and those of implementing and monitoring emissions reductions for less-proven technologies. Transaction costs are relevant because they increase the price of participating in low-carbon technology markets. Transactions related to technologies with lower TCs are more cost-effective than those related to technologies with higher TCs (cf. Hart, 2008). Small- and micro-scale LCTs are often exposed to proportionally higher TCs (Lof, 2009; Miller, 2008; Schneider, Schmidt, & Hoffmann, 2010).

Evaluation studies have tended to argue that the 'technological optimism'[1] portrayed by *ex ante* assessments does not fully take TCs into account and must be placed in the context of 'market realism'. For instance, conventional top-down and bottom-up modelling studies have assumed that the implementation of low-carbon technologies is costless, while other studies have assumed that high TCs can be reduced through policy interventions (e.g. Hourcade, Jaccard, Bataille, & Ghersi, 2006; Worrell, Ramesohl, & Boyd, 2004). Consequently, the results of these evaluation studies may underestimate both the potential and the associated costs of reducing GHG emissions. It is arguable that TCs must be evaluated, otherwise any claim that particular GHG emissions reductions are cost-effective may bear no relation to what can be plausibly achieved in practice (Kesicki & Strachan, 2011; Worrell et al., 2004).[2] In the present analysis, close attention is paid to whether or not there are negative costs for energy efficiency measures (as estimated in some conventional simulation exercises; see Figure 1) in the presence of TCs.

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[1] 'Technological optimism' is understood to mean that a growing number of technological improvements are sufficient to mitigate climate change by means of large-scale reductions in GHG emissions.

[2] A recent bottom-up modelling study carried out by McKinsey & Co (2009) estimated that energy efficiency improvements could reduce GHG emissions by up to 14 $GtCO_2$-eq per year – or nearly 40% of the global GHG abatement potential by 2030 – at negative net costs for investors. However, this study overlooks long-standing critiques of conventional bottom-up models, in particular the treatment of market and behavioural failures that impede the materialization of such potentials (e.g. negative externalities not reflected in energy prices, asymmetric and imperfect information about the performance and risks of mitigation technologies). The study does not discuss the rate of adoption or diffusion of new technologies and assumes that technologies deliver the estimated potential within ten years. A significant methodological aspect of the study relates to 'full' GHG abatement costs: initial equipment and operating costs (including energy saving costs) represent full costs. Transaction costs, however, are completely omitted. Compared to modelling studies that incorporate diffusion obstacles and market imperfections, the study overestimates efficiency improvements and resulting GHG emissions reductions (Murphy & Jaccard, 2011). Indeed, much of the differences between modelling studies – and much of the debate among technologists and economists – is related to the market and behavioural failures are treated (Hourcade et al., 2006; Huntington, Schipper, & Sanstad, 1994).

Despite theoretical arguments, and the growing importance of the policy dimension (IPCC, 2007; Mitchell et al., 2011) and the business perspective (WRI/WBCSD 2004), there is still no detailed analysis of TCs related to low-carbon technologies. Although this article surveys an emerging body of empirical literature, what is known is still fragmented across disciplines (e.g. new institutional economics, industrial organisation, environmental economics, and environmental management and policy) and technology markets. At the conceptual level, academics have called for clarification and further research to address the typology and measurement of TCs (Macher & Richman, 2008; McCann et al., 2005) and this article is an attempt to fill that gap. It should also be noted that there is very little detailed literature on the quantification of TCs associated with climate policy-driven mitigation technologies (cf. IPCC, 2007; GEA, 2012).

A comprehensive meta-analysis of studies on TCs related to policy-driven LCTs, with a focus on energy efficiency, renewable energy and carbon markets, is presented. Given the variety of conceptual approaches, an attempt is made in Section 2 to clarify the taxonomy of TCs related to LCTs. In Sections 3 and 4, the nature and scale of TCs in various technological contexts are analyzed, the different methods used to quantify TCs are investigated, and the reasons for the wide variations seen in quantitative estimates are examined. Finally, In Section 5, it is concluded that TCs are present in energy and carbon markets and thus must be considered in policy design and assessment studies. Indeed, there appears to be a 'Transaction Costs Policy Paradox'. This paradox means that despite the stylised policy and academic debate on whether TCs are an additional source of market failure; and therefore whether governmental intervention is required, there are measures and strategies that can actually reduce the sources and scale of TCs.

2. The analytical approach

This article is an explicit response to calls for a better understanding of the presence, significance, and scope of TCs in LCT policy-driven markets (IPCC, 2007; Mitchell et al., 2011). The analysis supports the call for a systematic analysis of TCs in order to improve policy choices and the design of instruments (de Jager & Rathmanm, 2008; Mitchell et al. 2011) and is motivated by the lack of knowledge about the measurement methods used to estimate TCs (Joskow, 1991; Masten, Meehan, & Snyder, 1991; McCann et al., 2005). It is hoped that the work presented here contributes to applied public policy research and advances the so-called 'natural progression' of TC economics (Williamson, 2010) with its interdisciplinary focus (Williamson, 1996).[3] The scope of the research is limited to TCs borne by investors or project developers whose actions are motivated by policy instruments (e.g. market-based incentives) designed to encourage LCTs (although where ever possible, TCs that arise from voluntary actions, i.e. those not driven by policies, are also considered. For policy instruments that are designed to diffuse and commercialize energy efficiency technologies (e.g. heating equipment, compact fluorescent lamps, insulation materials, household appliances), the focus is on labelling programmes, tradable schemes for energy efficiency improvements, mandatory electricity conservation programmes and compulsory energy audits. For policy instruments that support the diffusion and commercialization of renewable energy technologies (e.g. wind, bio and solar energy), the focus is on tradable green certificate (TGC) schemes, renewable portfolio standards and feed-in-tariffs.

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[3] It should be stressed that no attempt is made here to revive the 'market-failure debate' about TCs, i.e. the stylised academic debate on whether TCs are an additional source of market failure and whether government intervention is required (e.g. Howarth & Sanstad, 1995; Jaffe & Stavins, 1994). A 'market failure' is defined as a flaw in the market that does not allow efficient or optimal allocation of goods and services. A behavioural failure is defined as a decision-making action by firms and consumers that leads to a divergence from utility/profit maximization goals.

Transaction costs and their analysis are fundamental components of New Institutional Economics, which focuses on how decisions and transactions made by market agents are frequently based on imperfect and asymmetric information and how institutional frameworks influence the behaviour of these agents (Ménard, 2004; Williamson, 1981). The study presented here rejects the view that market flaws can be studied using transaction cost analysis (TCA) and departs from Common's (1934) approach , which established the 'transaction' (or 'contracting') as the basic unit of analysis for the study of economic organization. At a basic level, the approach here is based on the observation that contracting decisions (or transactions) made by market agents are rationally-bounded and based on imperfect information (North, 1990; Selten, 1990; Williamson, 1981; Williamson, 1993).

A critical hurdle in TCA is conceptual rather than empirical, with studies often focussing on different aspects of transaction costs. For instance, Coase (1937) focuses on 'pre-contractual' activities (e.g. the search for information and inspection);Williamson (1979) stresses the relevance of post-contractual activities (e.g. execution, control and enforcement); and Matthews (1986) and Furubotn and Ritcher (2010) take a more holistic approach and include both pre- and post- contracting activities and the drawing up of the contract as such.

More problematic are the differences in how transaction costs are defined. For example, Ostertag (1999, p. 2) thinks of TCs as a sub-group of 'hidden costs' which represent "a collective term for all impacts resulting from energy conservation measures which have not yet been fully accounted for in cost analyses". The author refers to 'time' devoted to determine the most efficient product on the market as an important source of TCs. However, the author also stresses that other potential sources (e.g. monitoring and maintenance) may (or should) not be considered TCs but 'production' costs of energy efficiency improvements. Mundaca (2007b), following Matthews' (1986) approach, to the identification of TCs associated with *ex ante* and *ex post* activities of arranging, including monitoring and enforcing a contract. Langniss (2003) includes costs related to activities directly attributable to the implementation of a renewable energy scheme. Skytte et al. (2003) include TCs related to planning (e.g. search for information, negotiation), implementation and production (e.g. monitoring) phases of a project. Interestingly, Slytte et al. (2003) define TCs that arise from the implementation phase in particular as 'opportunity costs', on the grounds that opportunity costs are determined by 'construction' and/or 'commissioning time'. TCs can either be 'real expenditures' or 'work load'. The literature on the Kyoto Protocol includes the pre-implementation, implementation and production phases of a project in its definition of 'transaction costs' (Del Río, 2007; Krey, 2005; Michaelowa, Stronzik, Eckermann, & Hunt, 2003). Yet other studies assimilate or include 'administrative costs' in their definitions of TCs (Joskow & Marron, 1992; McCann et al., 2005; Stiglitz, 1986).

Given the different ways of conceptualizing TCs, it would be useful to have a taxonomy of TCs that are applicable to LCTs. TCs are understood here to represent the *ex ante* negotiation, contract formation and *ex post* execution control and enforcement costs incurred by parties (or technological entities). The conceptual approaches of Matthews (1986) and Furubotn and Richter (2010) are used to define pre- and post-contract boundaries of potential sources of TCs. Building upon the concepts and typologies of TCs provided by Dahlman (1979), McCann et al. (2005) and Thompson (1999), a taxonomy was developed. The taxonomy is consistent with, and allows the different conceptual choices found in the above-mentioned studies to be accommodated. It is acknowledged that it is sometimes very difficult to draw a clear line between different sources of TCs. The taxonomy consists of five types of costs:

- Search for information costs: these include costs accrued due to information gathering and research about, and analysis of, the relevant technology, carried out by economic agents or parties.[4] Sometimes referred to as 'due diligence', the search for information is the process of evaluating a prospective technology decision by collecting information about its policy, financial, technical and legal aspects.[5]
- Negotiation costs: negotiation is the process by which parties agree on the terms of a contract or a project. Such costs include time spent negotiating, subcontracting of consultants or lawyers' fees, bargaining costs, and decision costs. Uncertainty associated with LCTs tends to create higher decision-making costs compared to standard technologies.
- Approval and certification costs: costs generated when the transaction needs to be approved by an institutional body prior to its implementation. They are often linked to the policy design and implementation requirements and may include costs due to regulatory delay (e.g. costs associated with public bureaucracy).

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[4] 'Economic Agents' or 'Parties' refer to the actors involved, e.g. government bodies, firms, consumers/households, public organizations.

[5] Although TCs borne by public authorities are outside the scope of this analysis, it should be noted that TCs related to policy design and implementation (e.g. when searching for technical information) may be borne by authorities and not (entirely) by individual agents of parties. For instance in Great Britain, the Department for Environment Food and Rural Affairs (DEFRA) developed the 'target-setting model' to determine various energy-related aspects attributed to eligible energy efficiency measures and supported the design and implementation of the Energy Efficiency Commitment (now known as the 'Carbon Emission Reduction Target' scheme; see Section 3.1.1). The model parameters used to develop the needed technical data included: number of electricity and gas customers, domestic fuel mix, fuel prices, estimated number of measures to be implemented, housing stock, current technological specifications, unit cost of measures, lifetime of measures, fuel carbon content, related carbon savings, and discount rate. All related TCs were borne by DEFRA.

- Monitoring and verification (M&V) costs: costs associated with the monitoring of policy compliance (from the subject participant's point of view), the environmental outcome, contractual agreements, and implementation of M&V technologies or management systems (e.g. energy or carbon audits). M&V costs are also known as 'metering costs' (e.g. for the specific case of M&V of energy savings or renewable electricity). These costs can also take the form of the time and resources needed to develop and implement an enforcement strategy in the case of non-compliance.
- Trading costs: costs that occur in the markets where quotas, allocations, or certificates are traded (e.g. carbon markets). Trading of certificates *per se* can occur through dedicated trading platforms or trading agents, or through brokers who take a fee for performing the transaction of certificates. Brokerage fees are a remarkable example of this category. Sources of TCs may involve the search for a certificate trading partner. Contract negotiation with certificate trading partners and liability risks in case of non-compliance can also be potential sources of TCs. [6]

This 'contracting sequence' approach lead to a 'life-cycle approach' regarding technology implementation and operation. Transaction costs may arise at various stages in a project, including planning, implementation, monitoring, verification, certification, and in certain cases, trading (e.g. of energy savings, carbon emission reductions, or green electricity). To some extent, this is consistent with Williamson (1981), who postulates that a transaction is a transfer of a good or service across a technologically-separable interface. However, it is

[6] Note that if the policy instrument(s) encouraging a low-carbon technology does not involve the trading of certificates, this potential category of TCs is not needed. In our taxonomy, we attempt to draw a distinction between TCs (e.g. search for information) that originate from technology implementation as such (i.e. search for project-based technical information) and TCs that originate from the trading of certificates in particular (e.g. search for trading partner).

recognized here that it is sometimes difficult to categorize TCs according to the project life-cycle (e.g. information search costs may apply throughout).

Finally, and in order to confront the 'technology optimism' v 'market realism' gap described in the previous section, a simple microeconomic analytical model was developed to understand the potentially negative effect of TCs on carbon emissions reductions resulting from LCTs (see Figure 1). Note that in the example given, the first units of carbon emissions are at negative costs. In this simple model, the equilibrium level is represented by Q_E at price P_E, at which marginal costs and benefits are equalized. This equilibrium can be called the 'carbon emissions reduction equilibrium in the absence of TCs'. However, with the addition of TCs (*T*) - e.g. searching for and assessing equipment, negotiating and enforcing agreements, monitoring emissions reductions - the equilibrium level changes. If TCs are borne by the supply side, the actual *MgC* curve shifts upward and to the left, *MgC* + *T*. It is assumed here that TCs slightly decrease as carbon reductions increase, as TCs are assumed to be fixed (e.g. fixed M&V costs) and the slope of *MgC* + *T* is slightly less steep due to economies of scale associated with greater reductions (e.g. bulk discounts offered by brokers). The presence of TCs implies that carbon reductions fall from Q_E to Q_T and that the marginal costs of carbon reductions increase from P_E to P_T. Both effects take place regardless of the *MgC* and *MgB* functions. Note that in this simple model, the introduction of TCs means that the first units of carbon reductions can no longer be yielded at negative cost. From an empirical point of view, specific attention is given to whether negative costs for energy efficiency measures exist (or not) in the presence of TCs.

[Please Insert Figure 1]

3. Results

3.1. Transaction costs of energy efficiency technologies

3.1.1 Nature of TCs

3.1.1.1. TCs related to planning

In their study about the penetration of Compact Fluorescent Lamps (CFLs) and washing machines into the Californian market, Sathaye and Murtishaw (2004) found that TCs arose from the information processes necessary to acquire, assess and use information about the product.[7] Consistent with their results, Hein and Block (1995) studied large, energy-intensive firms in the Netherlands and found that the main sources of TCs are from gathering and assessing information. Marbek Resource Consultants (MRC, 2004) also identified the search for information and project design as critical sources of TCs. Similarly, Mundaca and Neij (2006) found that the search for information was the principle source of TCs for electricity companies under the 'Free-of-Charge Energy Audit' (FCEA)[8] in Denmark, where information costs were related to identifying customers suitable for an energy audit; they also found that there were information costs in the British 'Tradable White Certificate' (TWC) scheme (called

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[7] In their study, 'product information cost' referred to the costs of making consumers aware of potential energy savings and establishing the amount of those savings; 'Vendor information cost' referred to the cost to the vendor of informing the client; finally, 'Consumer preference' referred to consumers' limited cognitive ability to assess and gather information.

[8] Under the FCEA, grid companies are obliged to conduct audits of organizations that consume more than 20MWh of electricity annually. Audits are financed by end-users. The FCEA includes: 1) a general overview, 2) analysis of findings, 3) development of savings plans, 4) follow-up, 5) report to the audited company, and 6) report to a common database. In 2003, expenditure on the program amounted to EU€22 million (of which more than half was spent on energy savings measures; see Mundaca & Neij, 2006).

the ‘Energy Efficiency Commitment’ [EEC] at the time[9]). Mundaca (2007b) also found TCs in the planning phase of eligible technologies, due to the need to both establish which measures to take and identify customers likely to implement the technologies; parties in the British TWC scheme sometimes subcontracted these activities to ‘managing agents’ and also had to persuade customers to effectively implement measures. Wallach, Chernick, White, & Hornby (2008) found that the costs of bid preparation and materialization of credit guarantees are relevant sources of TCs for those utility companies that are searching for the best procurement strategies aimed at the provision of the lowest electricity market prices for residential customers.

3.1.1.2. TCs related to implementation

Björkqvist and Wene (1993) found that the time taken to decide whether or not to adopt efficient technologies was a significant source of TCs for Swedish families seeking to improve the energy efficiency of their heating systems. Hein and Block (1995) focused on costs related to decision-making by energy managers and noted that costs varied depending on the approval process and the available human and financial resources (e.g. the extent of TCs was determined by whether an investment was approved by a manager or the CEO determined). Mundaca (2007a) identified TCs created by contract negotiations for the development of energy saving plans, originating in interactions between Operations and Maintenance (O&M) teams and equipment manufacturers; similarly in the British TWC scheme, where consultants were hired to facilitate arrangements between parties and local

[9] The EEC (now replaced by the ‘Carbon Emissions Reduction Target’ scheme) imposed an energy saving quota on suppliers (gas and electricity) to the residential sector. The scheme allowed participants to trade certified energy savings as a means of cost-effectively reaching energy-saving targets set up by the authorities.

authorities, provide advice on the type of measures to be implemented, and help to explain the regulatory framework (Mundaca, 2007b). Parties also negotiated contracts with insulation contractors[10]. MRC (2004) highlighted two other sources of TCs related to baseline settings and the development of monitoring plans and identified TCs related to contract negotiations (see also Ostertag, 1999). Finally, Wallach et al. (2008) have emphasized that legal and regulatory affairs are critical sources of TCs in the implementation of those procurement contracts that aim to deliver electricity more efficiently.

3.1.1.3. TCs related to M&V

Regarding monitoring, MRC (2004) highlighted activities such as metering and field measurements needed to qualify and quantify energy savings and GHG reductions; verification costs arising from activities carried out by a third party who reviewed and checked the integrity of the monitoring carried out by the project developer were also mentioned. Joskow and Marron (1992) studied electricity conservation programmes run by utilities in the US and (although they did not evaluate TCs explicitly) included M&V as an administrative cost that covers the promotion and delivery of conservation measures. In an analysis of heat suppliers, Ostertag (1999) identified sources of TCs with the personnel required to supervise or maintain a new energy installation; M&V costs were considered to be part of the 'base price'[11]. Other sources of TCs were associated with connecting to the

[10] This was highly critical as insulation measures (100% sub-contracted) delivered the most cost-effective energy savings, representing nearly 60% of total delivered energy savings.

[11] Ostertag (1999) distinguishes between transaction costs as 1) 'base price', which includes administrative costs such as contract negotiation, information collection, monitoring of new installations, investment costs, fuel and electricity costs, repair, maintenance, insurance and rent costs, 2) 'operating price', which represents fuel delivery and electricity costs , and 3) 'metering price', which are costs associated with the measurement and control of emissions, and the cost of standardizing metering equipment.

grid, or extra work created by a more energy-efficient boiler. In the British TWC scheme, the main source of TCs was random quality checks related to installation and customer satisfaction (Mundaca, 2007b).[12]

3.1.1.4. TCs related to trading

The only identified example was in the British TWC scheme, where energy suppliers were able to trade energy savings (or allocated obligations) in order to achieve cost-effective savings. However, Mundaca (2007b) has argued that perceived TCs led to low levels of trading such that they were thought to result from two activities, namely contract negotiation and liability risks. The study showed that suppliers were reluctant to trade certificates because they feared it would disclose strategically-sensitive information (e.g. compliance costs). Trading was also affected by suppliers who considered it too risky to trade without being sure who was legally responsible should the implementation of measures not go according to plan.

3.1.2 Estimated scale of TCs

In the limited numbers of studies that addressed quantitative estimates, a variety of metrics and ranges for the measurement of TCs (discussed in more detail in Section 4) were found. The specific policy and/or technology scope of each study analysed provided different sources and estimates of TCs (see Table 1 for a summary of aggregated estimates). In disaggregated terms, the number of available studies is even lower. Hein and Block (1995) reported that information costs varied depending on the type of equipment (1% for a co-

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[12] Note that under the EEC there was no M&V of energy savings. Energy savings, associated with well-known technologies in the residential sector (e.g. CFLs, cavity wall insulation) were estimated on an ex-ante basis.

generation installation and 6% for a monitoring system) and found that for one firm, estimated TCs related to information costs accounted for 3-4% of the overall cost of energy investments, while those related to decision-making accounted for 1-2% of total investment costs. Regarding planning and implementation, Björkqvist and Wene (1993) estimated that, on average, a family needed 18 hours to choose an efficient heating system. Using labour rates to approximate TCs, they estimated TCs to be US$167-360. While this approach is open to criticism (on the grounds, for example, that consumers do not typically take time off from work to make such a decision) Björkqvist and Wene (1993) have claimed that TCs represented 13-28% of an estimated purchase cost of $1300 per family. MRC (2004, pp.14, 22, 26) provided disaggregated estimates for energy efficiency projects that claimed reductions equivalent to 10kt CO_2-eq. TCs related to the planning phase were estimated to range from CA$1000 to CA$5,000. Although a similar range for the implementation phase was also provided in MRC (2004), it stressed that uncertainty (e.g. in relation to baselines) could increase TCs by up to CA$15,000.[13]

[Please Insert Table 1]

Several strategies to limit the nature and reduce the scale of TCs, including standardized full-cost accounting systems, *ex ante* M&V approaches, streamlining of procedures, standardized trading contracts, and a trading platform, were identified in the review. This suggests that even if TCs are considered a potential source of market failure, policy intervention may be beneficial.

[13] MRC (2004) estimated M&V-type TCs to be CA$3,000-10,000 for the first year, and CA$2,000-5,000 for subsequent years.

Interestingly, there were no reported negative costs for the specific case of energy savings (e.g. as suggested by the McKinsey & Co., 2009). Whilst some studies showed cost-effective savings (e.g. Mundaca, 2007b), all reported energy saving costs were positive. This seems to support the simple theoretical model used (see Section 2), in which the least-cost mitigation options are pushed into the positive cost territory due to the presence of TCs.

3.2. Transaction costs of renewable energy technologies

3.2.1. Nature of TCs

3.2.1.1. TCs related to planning

Skytte et al. (2003) identified TCs related to the planning phase of renewable energy technologies as information costs. In their study, TCs arose from the search for information about the choice of technology and the search for partners. Langniss (2003) compared TCs related to the German Renewable Act and the Renewable Portfolio Standard (RPS) in Texas and identified the search for information as a critical source of TCs, particularly for new firms entering the market.

3.2.1.2. TCs related to implementation

Skytte et al. (2003) identified high TCs related to the negotiation process. Finon and Perez (2007) argued that contract and negotiation arrangements between renewable electricity producers and obligated parties were an intrinsic source of TCs for certain policy instruments, particularly TGCs or renewable energy obligations. Similarly, Nagaoka (2002) identified contract negotiation costs as an important source of TCs. In his study, contracts were negotiated and re-negotiated by Brazilian electricity suppliers when the contractual amount of biofuel was not delivered, regulations were changed, or technical failures arose. Negotiation costs, borne by both the electricity supplier and the renewable electricity generator, were also identified in the Texan RPS (Langniss, 2003). Bidding and negotiations were resource-consuming and the preparation required for bidding could, by itself, generate considerable costs. Ram and Selvaraj (2012) have stressed the importance of TCs associated with the legal and technical expertise that is needed to understand and comply with grid interconnection requirements. Skytte et al. (2003) identified TCs related to official approval procedures, which included the time and management needed to obtain approval for renewable energy projects to meet regulatory requirements, and also included time and costs related to compliance strategies (due to a change in regulations or even new scientific evidence) as sources of TCs.

3.2.1.3. TCs related to M&V

In the Texan RPS, monitoring costs were borne by the regulator who monitored the certification process; Langniss (2003) identified approval procedures as a source of TCs, which included approval from regulators of renewable energy projects that were the subject of energy policies (Skytte et al., 2003). This also applied to TGC schemes that have been established in several countries, including the Netherlands and Sweden.[14] Under the Swedish and Dutch schemes, TCs were characterized as additional costs to be met by obligated parties beyond the costs of meeting the obligation itself (Oikonomou & Mundaca, 2008). In Sweden, TCs represented the administrative costs met by electricity producers and

[14] In Sweden, the TGC scheme was introduced in 2002 and was more generally accepted than other economic instruments (Oikonomou & Mundaca, 2008). In the Netherlands the scheme was introduced in three phases, starting in 1998, on a voluntary basis for distribution companies.

suppliers in handling the renewable energy quota obligation on behalf of end-users (Kåberger, Sterner, Zamanian, & Jürgensen, 2004; Bergek & Jacobsson, 2010)[15]. This is consistent with the results of Finon and Perez (2007), who analyzed consumer cost control from a TC perspective and identified TCs related to meeting legal and technical conformity requirements (Finon & Perez, 2007; Langniss, 2003; Skytte et al., 2003).

3.2.1.4. TCs related to trading

TGC schemes can create TCs when parties hire a broker to conduct transactions (Nielsen & Jeppesen, 2003; Skytte et al., 2003). Another source of TCs lies in the resources that parties must allocate to find trading partners or register their trading activities (Nielsen & Jeppesen, 2003). TCs are also likely to arise if TGC schemes are not fully harmonized, which in turn creates trade restrictions (Nielsen & Jeppesen, 2003). Interestingly, the literature does not provide any further empirical details. Skytte et al. (2003) have argued that parties do not have the experience or resources to trade directly, which prevents the identification and study of 'real' TCs. A tendency to avoid trading may be the result of 'perceived' TCs (similar to the British TWC scheme), high market volatility, and prices risks due to low market liquidity (cf. Finon & Perez 2007).

3.2.2. Estimated scale of TCs

The number of studies providing quantitative estimates is low. For aggregated estimates, it was only possible to identify seven studies (see Table 2 for a summary). Besides

[15] Note that the initial design of the Swedish TGC scheme allowed electricity retailers to charge customers for the certificate handling service they provided. However, it was found that a significant amount of money paid by end-users to suppliers did not in fact reach electricity producers (Kåberger et al. 2004; Nilsson & Sundqvist 2007).

methodological aspects (to be discussed in Section 4), the specific policy and technology contexts of the studies identify different sources of TCs and thus provide different ranges of estimated TCs. Regarding disaggregated estimates, Skytte et al. (2003) estimated that TCs associated with the production phase represented 7% of total investment costs. Of these, enforcement costs were highest (>6%), followed by monitoring (~5%) and adjustment (~4%). However, the study showed high variations for low and upper bound values (e.g. >30%). Langniss (2003) found that negotiation and contracting costs were 0.03-0.05% of the traded renewable energy value for both the generator and the retail supplier.

[Please Insert Table 2]

3.3. Transaction costs related to LCTs in carbon markets

3.3.1. Nature and scale of TCs under the CDM and JI

The Clean Development Mechanism (CDM) and Joint Implementation (JI) are project-activity based mechanisms defined in the Kyoto Protocol.[16] Some authors argued that the cost-effectiveness of both the JI and the CDM is strongly affected by TCs, which are often underestimated or ignored (Fichtner, Graehl, & Rentz, 2003; Michaelowa et al., 2003). Dudek and Wiener (1996) were among the first to analyse TCs in this context and identified TCs related to the search for information, negotiations, approval, measurement, and insurance costs. Hart (2008) has subsequently argued that the CDM regulatory framework encompasses high TCs, while Sreekanth, Sudarsan, & Jayaraj (2012, p. 8) argue that despite

[16] A project activity is defined as "a measure, operation or an action that aims at reducing greenhouse gases (GHG) emissions" (CDM EB, 2003, p. 5). The Kyoto Protocol and the CDM modalities and procedures use the term 'project activity' rather than 'project'. A project activity can therefore be a component or aspect of an undertaken or planned project.

the existence of potentially cost-effective mitigation measures, "the attractiveness of project-based mechanisms may be substantially lowered by TCs arising from implementation procedures and bureaucracy".

Regarding the nature of TCs, the German Federal Ministry of the Environment, Nature, Conservation and Nuclear Safety (BMU, 2007) identified several sources of TCs for both flexible mechanisms. It found that there were TCs when developing the Programme Design Document (PDD) and determining the baseline, gaining approval from the relevant Designated National Authority (DNA), seeking validation, and registering at the CDM Executive Board. The PDD, the source of most TCs, includes a time-consuming baseline calculation of emissions and a demonstration of additionality required to validate the project. The present study finds that the more complex the baseline (and consequently the required monitoring) the higher the TCs. Similarly, Boyle, Kirton, Lof, & Naylor (2009) and Schneider et al. (2010) have argued that the development of the PDD, together with complex baseline determination and demonstration of additionality, is an important source of TCs. Hart (2008) has argued that the lengthy registration process (and associated fees) significantly increases TCs for CDM projects (see also Schneider et al., 2010).

Fichtner et al. (2003) found that TCs associated with technical and administrative costs, follow-up and reporting, represent a heavy burden for project developers. In the specific case of CDM wind-energy projects, Mundaca and Rodhe (2005) identified similar TCs that included *inter alia* negotiations with potential developers and Certified Emission Reduction (CER) credit buyers, ensuring host country approval, establishing baseline emissions and proving additionality, validation of the baseline, development of monitoring plans, and contracting international auditing.

Wara and Victor (2008) reviewed experience of the CDM and found TCs associated with the search for information needed to develop baselines and prove additionality. They emphasized the TCs that arise from the CDM Executive Board's evaluation and registration process and argued, like many authors, that these costs are excessive for small-scale CDM projects. Consequently, there is pressure from CDM investors to reduce these TCs and accelerate the review and approval process. Sovacool (2011) suggested that the CDM regulatory framework creates high TCs, as it requires projects to be designed, reviewed, audited and evaluated in a very particular way. Hart (2008) has argued that precise and regular emissions monitoring is central to the efficient functioning of carbon trading markets such as the CDM and JI) but that this too is an important source of TCs.

When it comes to the estimated scale and resulting burden of TCs, a variety of estimates were found. Krey (2005) identified and quantified TCs in 65 CDM projects in India. Some TCs were almost negligible compared to the CER price, as their share of the price ranged from 2.2% to 13% (Krey 2004). For projects with emissions reductions lower than 1 $MtCO_2$ over the crediting period, most of the TCs were comprised of PDD costs, costs related to finding a buyer, the cost of validating the project, and the adaptation fee.

Williams (2009) has provided disaggregated and absolute estimates for CDM wind energy projects in India. Costs associated with PDD ranged from €14–22, for validation from €44–59, and for verification they were in the region of €30–44 per project. Mundaca and Rodhe (2005) found that, depending on the size and performance of small-scale wind energy projects, TCs per CER vary considerably (by a factor of 15). Del Río (2007,) has argued that TCs should not exceed 10% of their CER revenues for CDM renewable electricity projects to be financially feasible. For small-scale projects, in which the volume of CERs decreases much faster than the related TCs, the burden of TCs can swallow up to 50% of CER revenues.

Consistent with the sources of TCs identified above, Michaelowa et al. (2003) has estimated TCs for CDM projects funded by the Prototype Carbon Fund (PCF), which is operated by the World Bank. Relying on data provided by the PCF, Michaelowa et al. (2003) found geographical differences in TCs: those including pre-implementation, implementation and certification in the electricity sector in North Africa were estimated to be €0.52/tCO_2, compared to €0.29/tCO_2 in South America (for almost an identical reduction in CO_2 emissions).

Michaelowa and Jotzo (2005) have reported that energy efficiency projects, implemented under the Swedish 'Activities Implemented Jointly' (AIJ)[17], that produced reductions of less than 100tCO_2/year had considerably higher transaction costs (>€80/tCO_2) than projects with reductions of 2,500-5,000 tCO_2/ year (<€3/tCO_2). With regard to total TCs, Fichtner et al. (2003) found that average TCs were 13% (for energy efficiency projects) and 20% (for renewable energy projects) of total project costs.Aggregated quantitative estimates and related key sources of TCs are summarized in Figure 2.

[Please Insert Figure 2]

In order to reduce the number of sources of TCs and their resulting scale, different strategies can be found in the literature, including simplified baseline and monitoring methodologies (e.g. for small-scale CDM projects), standardized procedures, project bundling, and hi-tech

[17] Prior to ratification, some countries launched a pilot phase commonly referred to as 'Activities Implemented Jointly' (AIJ) in order to test the provisions of the Protocol.

communication trading platforms. Again, these potential interventions indicate the presence of the 'Transaction Costs Policy Paradox'. This means that even if we agree that TCs are not an additional source of market failure (and thus policy intervention may not be needed), our review reveal several measures and strategies that can actually reduce TCs.

3.3.2. Nature and scale of transaction costs under the EU ETS

Using Ireland during Phase I of the EU ETS (2005-2007) as a case study, Jaraite et al. (2010) identified three types of TCs:

- Early implementation costs (prior to 2005): these were fixed and included internal costs (e.g. management, staff training), consultancy costs, and capital costs related to the monitoring and recording of data and storage equipment. These were one-off costs and the measurement of baseline emissions was one of the most important elements of the EU ETS.
- Monitoring, reporting and verification costs: these were periodic and included the preparation of an annual report that needed to be verified, together with the emissions reported. These represented a combination of internal administration and consultancy costs.
- Trading costs: these were variable and incurred only by firms that were trading allowances. They depended on the number of transactions performed, the volume of the trade, and the fees involved which varied from one broker to another.

Hepburn, Grubb, Neuhoff, Matthes, & Tse (2006) analyzed the auctioning of allowances under Phase II of the EU ETS, and argued that political and policy decisions regarding the allotment of allowances between participants generated an intensive lobbying campaign.

Consequently, the resources devoted by participants in their attempts to lobby policy-makers and politicians represented an important source of TCs.

Schleich and Betz (2004) have examined TCs in small and medium-sized (SMEs) companies under the EU ETS and identified two main sources of TCs. First, costs related to the application procedure for allocations and permits, those associated with service charges for registered accounts, and those due to monitoring, verification and CO_2 emissions reporting costs (including cost-related issues created by allowance trading). Second, attempts to maximize the share of income generated by the trading scheme. In this latter case, the sources of TCs were related to the need to map out and assess (potential) mitigation measures, carry out dedicated techno-economic studies, and search for trading partners and carbon transactions. Schleich and Betz (2004) argued that while some TCs only accrued once (e.g. those associated with the application for allocations and permits), others (e.g. M&V costs) were accrued annually, and yet others depended on the number of trades or trading volume (e.g. the cost of finding trading partners).

One of the main findings of Jaraite et al. (2010) was that the highest TCs arose in the early phases of implementation. TCs incurred by organizations in relation to baseline setting and the functioning of the EU ETS market represented the two most significant sources. In absolute terms, these costs tended to be higher for larger organizations than SMEs. However when TCs were distributed in terms of CO_2 emissions, Jaraite et al. (2010) found the opposite: early implementation costs for large organizations represented €0.03/tCO_2 but €0.51/tCO_2 for small companies. This finding highlights the importance of project size and the (potentially) unequal distribution of TCs borne by technologies of different sizes. Due to the nature of their projects, large and medium-sized companies tended to spend more on monitoring than small organisations. In small organisations, half of M&V costs were devoted to verification. On average, implementation and M&V costs represented €0.08/tCO_2, less than 1% of the allowance price (this amounted to €11.60 in January 2009 when this study was conducted). Trading costs tend to vary as they are proportional to the amount traded and/or depend on the CER market value. Sovacool (2011) estimated that traders and brokers took a fee of 3-8% of the value of CERs. Jaraite et al. (2010) cited a brokerage fee (per ton of traded allowance) that ranged from €0.10 in January 2005 to €0.06 in August 2006.

4. Critical factors influencing transaction costs

The findings of the review strongly suggest that the sources and estimates of TCs are case and context-specific. Why then are all these cases unique?

4.1. Endogenous factors

There are some internal factors associated with the implementation and operation of LCTs that influence the nature and scale of TCs. It is clear that the size of the project is an important factor determining the scale of TCs. Then, because some TCs relate to fixed costs (e.g. baseline development) the actual burden may decrease as the volume of carbon reductions increases. In the particular case of energy efficiency, various studies have concluded that the size and performance of the technologies measured (e.g. in terms of carbon emissions reductions or energy saved) ultimately determines the burden of TCs (Björkqvist & Wene, 1993; Michaelowa & Jotzo, 2005; Ostertag, 1999). In carbon markets, the value of carbon credits must also be taken into account. For instance, if an average CER price of US$20 is assumed (the situation in 2008), then (based on the estimates shown in Figure 2)the burden of TCs for CDM projects could range from 0.4 to 10% (lower bound) to

22 and 170% (at the upper bound) per CER. Given a CER market price of US$5 (the situation in 2012), the burden could range from 2 to 40% (lower bound) and 90 to 680% (upper bound) per CER.

Technical aspects were identified in most (if not all) of the reviewed studies. Several factors seem to be relevant. First, baseline setting and the resulting M&V activities were critical. It is simply more complex to M&V energy savings than it is to measure the amount of renewable energy generated (Chadwick, 2006). TWC schemes, JI and CDM are project and credit-based mechanisms, where energy savings or emissions reductions are measured against a baseline describing what would have occurred if the project or technology had not been implemented. A complex project is likely to create complexity in baseline setting, the M&V approach and higher TCs.

Another factor that affects TCs relates to the potentially high number of intermediaries in energy efficiency investments. The choice of household technology often involves project developers, construction companies, equipment dealers etc., which increases the number and complexity of transactions (Lutzenhiser, 1992). These actors take important and strategic decisions that impact the costs of carrying out an economic transaction. However, while the participation of intermediaries (e.g. managing agents, local authorities, landlords, charitable organisations) added to the TCs observed under the British TWC scheme, it also helped to reduce them because in their absence, the TCs for obliged parties in relation to the search of customers willing to implement energy efficiency measures would have been much higher.

Some studies noted a 'learning effect' that reduces TCs over time. Michaelowa and Jotzo (2005) suggested this when analysing AIJ project activities and noted that in the first round of the JI project, TCs were much higher (e.g. >US$100/t$CO_2$) than later in the process (e.g. <US$10/t$CO_2$). This trend was also apparent in Jaraite et al. (2010), MRC (2004), and BMU (2007). The upper bounds of TCs estimated for AIJ projects (US$100–250/t$CO_2$) in these studies did not match more recent estimates (<US$5/t$CO_2$) (see Figure 2). As mentioned above, TCs related to negotiation and verification costs are key components of total TCs. Thus, in the long run, TCs related to project start-up should become lower due to greater experience of GHG offset schemes, the development of standard contracts, and better competition in associated legal services.

4.2. Exogenous factors

There are also a number of external factors associated with the implementation and operation of LCTs that influence the nature and scale of TCs. First, and above all, regulatory policy frameworks can drive the nature and resulting scale of TCs. For example, as Langniss (2003) has pointed out in relation to the German feed-in-tariff scheme, there were no TCs related to the search for information and negotiation of contracts because the identity of the buyer, the level of remuneration, and the deliverable amount of electricity were determined by law. The absence of *ex post* M&V costs under the British TWC scheme (Mundaca, 2007b) can be compared with their presence under the Italian TWC scheme (Pavan, 2008). Another example is the CDM and JI, where the regulatory framework necessarily introduces TCs (e.g. baseline setting, approval, M&V, certification, registration).

Additionally, organizations entering into multi- or bilateral agreements face higher TCs related to contract negotiations than those that prefer a unilateral mode of implementation (as in the CDM). Finally, the regulatory complexity of TGC schemes has often been highlighted as a source of high TCs (Mitchell et al., 2011). Overall, these findings are consistent with the work of Heller (1998), who was one of the first to argue that TCs depend on regulatory policy frameworks.

The requirement for access (or eligibility) to trading markets can also significantly influence TCs, and brokerage fees are often mentioned as an example. Skytte et al. (2003) estimated brokerage fees to be 5% of the total traded value in national trading, and as varying from 2% to 10% for international trading. Such fees depend on the type of market in which the trade is taking place and the maturity of markets. Organizations that lacked experience or personnel resources tended to use brokerage firms. Mundaca (2007b) found that, in the British TWC scheme, brokers facilitated arrangements between suppliers and local authorities and brokerage fees amounted to up to UK£10 per installed insulation measure or customer identified.

The reviewed studies either implicitly or explicitly highlight specific market/national conditions that influence the nature and scale of TCs. The maturity of low-carbon technology markets impacts pre-implementation TCs. A lack of technical and human capacity can be the driver for high TCs associated with the search for information and contract negotiations. Higher project risks (and consequently higher TCs) result from asymmetric or inadequate information, compared to established markets of fossil fuel or conventional technologies (Sonntag-O'Brien & Usher, 2004). Pan (2002) has stressed the efficiency of inter-ministerial coordination both as a central factor that affects TCs and in securing the dual objectives of

CDM projects (i.e. reduction of GHG emissions and contribution to sustainable development). Pan (2002) also found that government corruption, cultural barriers and unstable governments can increase TCs under the CDM, making the participation of developing countries inefficient (Hart, 2008).

The review also reveals the important role of parties on the level of TCs. Ahonen and Hämekoski (2005) have asserted that the distribution of TCs among parties is project-specific and clearly a matter of negotiation. In addition, Morrison et al. (2008) and Ducos et al. (2009) suggested trust as a significant factor in TC analysis and proposed that trust may reduce TCs as it facilitates contract negotiations and reduces search and associated administrative costs (cf. Michaelowa et al., 2003; Williamson, 1971, 1979).

4.3. Methodological factors

Conceptual choices impact the scope of the investigation and thus the nature, scale and resulting burden of TCs. For example, the majority of studies on the flexible mechanisms of the Kyoto Protocol identified similar sources of TCs (e.g. negotiation, approval, M&V activities). However, in light of Coase's (1960) definition and conceptual remarks from the reviewed studies (e.g. Ostertag, 1999), it could be argued that such TCs may not in fact be counted as TCs because CDM and JI project activities must include registration, verification, and certification of 'contracting activities' (these are required for the 'production' of CERs). This argument could thus be applied to the production steps involved in, or required for, tradable certificate schemes: in all of these markets, what is traded is 'certified emission reductions', 'certified energy savings' or 'certified renewable energy production', and not emissions reductions *per se* and therefore, the 'sources' of TCs are simply 'production steps'.

The quantification of TCs is a complex and expensive exercise. Many aspects deserve attention. Joskow (1991) has stressed that TC analysis needs a rigorous mathematical foundation. Macher & Richman (2008) acknowledge that there is a lack of both precision and empirical methods for testing transaction variables. Values or parameters are often taken from secondary sources, which makes the interpretation of results difficult. Moreover, with the exception of Langniss (2003) and McCann et al. (2005), the studies reviewed tended to focus on market transactions rather than TCs associated to developments and changes in institutional and legal systems (e.g. TCs associated with public accounting and enforcement). Another quantification issue is who bears the TCs (e.g. project developers or customers). Joskow and Marron (1992) and Mundaca (2007a, 2007b) identified this factor in their analyses of energy efficiency projects, whilst TCs borne by beneficiaries were partially addressed by Björqvist and Wene (1993). With this in mind, it is very likely that the reviewed estimates of TCs have underestimated the total TCs (cf. McCann et al., 2005).

A variety of methods have been identified to measure TCs, including the 'Total Resource Cost' model (Joskow & Marron, 1992), the 'Price-cost Margin' econometric model (Nilsson & Sundqvist, 2007), 'Carbon Abatement Curves' (Krey, 2005), and 'Cost-effectiveness Analysis' (Mundaca, 2007b). Each of these approaches make different assumptions and have different levels of uncertainty, degrees of complexity, and input data requirements.[18] These various quantification methods are consistent with the work of

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[18] Joskow and Marron's (1992) model compares the costs and savings of demand-side management programmes against known projections for the same types of costs and savings. Nilson and Sundqvist's (2007) model measures TCs using the margin between the price electricity retailers pay for green certificates and what they actually charge to the end-user for the certificate service. The price-cost margin is defined as a function of risk, returns and TCs. Krey's (2005) method estimates marginal carbon emissions reduction costs in relation to TCs. Mundaca's (2007b) analysis focuses on the cost of energy savings. Although similar to the approach taken by Joskow and Marron (1992), Mundaca's (2007b) method aims to quantify aggregated TCs based on the life-cycle of energy efficiency projects. However, unlike them, Mundaca (2007b) used actual residential energy prices to estimate net financial benefits for end-users.

McCann et al. (2005), who argued that different contexts and sources of TCs require different measurement methods.

Data collection is another major (and expensive) challenge. Data used to populate TC measurement methods comes from statistical information, surveys, interviews, and secondary sources. Some studies explicitly acknowledge small statistical samples and thus low confidence levels (e.g. Hein & Block, 1995; Mundaca, 2007b; Joskow & Marron, 1992).[19] Small samples are often due to the fact that stakeholders are reluctant to disclose information for strategic reasons.

Another issue is the 'Transaction Cost Accounting Problem'. Joskow and Marron (1992) describe this as arising from the fact that project developers, although they are fully aware of the existence of TCs, do not keep track of them. Consequently, costs are often underestimated (on average, by a factor of two or more). Mundaca and Neij (2006) noted differences in the levels of accounting (and awareness of TCs) when analysing the FCEA in Denmark and found that 35% of respondents could not evaluate TCs related to direct energy audit costs.

5. Conclusions

Transaction cost analysis needs greater conceptual and methodological consistency if the evaluation of energy and climate policies applicable to LCTs is to improve. Numerous conceptual discrepancies and methodological divergences were found in the literature, all of

[19] Joskow and Marron (1992) discuss the limitations of their study and the impact on results in detail. They argue that costs are likely to be underestimated because of internal accounting problems and that energy savings, (a critical factor in cost estimations) are likely to be overestimated. This provides an interesting insight into the factors that must be taken into account when carrying out studies in which the data collection and analytical methods present serious challenges.

which - to a greater or lesser extent - significantly impact results. An attempt has been made to clarify the typology of transaction costs related to LCTs, which can be used to support further research. Transaction costs are important factors in the design of policy and choosing the appropriate instrument. Further research is needed into the market, behavioural, and policy imperfections that create TCs and influence their order of magnitude. The identified ‘learning effect’ suggests that as LCT markets continue to evolve and mature, the scale (and thus the burden) of TCs is likely to decrease. Further empirical research will provide a better basis for this assertion.

TC analysis is mostly technology and policy context-specific. It is therefore not possible to make valid generalizations about TCs in the context of policy design and instrument choice. It was found that it is exceedingly likely that the nature and scale (and thus the burden) of TCs will differ due to a wide variety of endogenous, exogenous, and methodological determinants. Estimated TCs are typically expressed in various functional units or metrics, which adds to the difficulty of comparing studies. The variety of determinants also affects the level of uncertainty and the magnitude of estimates, even when similar technologies or technological dimensions are under scrutiny. In addition, data sources, assumptions, and the limitations of the analyzed studies suggest that the extant research has produced precise, but perhaps inaccurate, estimates. Due to the specificity of TC analysis of policy-driven LCTs, it is likely that measurement methods will also differ. A case-by-case analysis of policy when examining the nature and scale of TCs is therefore recommended.

If a comparative assessment of TCs between policies is wanted, a common analytical foundation is needed. This is critical to avoid misleading policy analysis. At a minimum, key elements to consider and define include the sources of TCs to be measured, eligible technologies under assessment, metrics, standard measurement methods, tools for data collection, parties that bear TCs, life-cycle stage (technology or policy) under analysis, and the maturity of policies. Given the relatively homogenous sources of TCs and functional units used in estimates, an initial comparative analysis of the TCs involved in the Kyoto Protocol's flexible mechanisms is feasible.

Finally, the analysis presented here suggests a 'Transaction Costs Policy Paradox' such that in spite of the policy and academic debate on whether TCs are an additional source of market failure, there are several measures and strategies that can actually reduce the sources and scale of TCs. For example, potential approaches to be assessed and implemented include: standardized full cost accounting systems, an *ex ante* M&V approach, project bundling, streamlining of procedures, and a clearing house platform. The analysis also suggests that, without hampering the integrity and performance of policies, the development of a clear and simple legal framework is a critical factor in reducing TCs. Although some authors have argued that the analysis of TCs in relation to the design and application of public policies has become more widespread (e.g. Williamson, 2010), it remains to be seen whether this will actually improve policy.

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Table 1 Estimated aggregated scale of transaction costs related to energy efficiency technologies

Case study	Nature of TCs	Scale of TCs
Electricity conservation programmes in the USA[a]	Promotion, delivery, and monitoring	30% of the costs of the commercial and industrial energy saving program. Higher in the case of residential programmes.
FCEA in Denmark[b]	Search for information, contract negotiation	15 to 20% of direct FCEA activity costs.
EEC (phase 1) in Great Britain[c]	Attracting customers, hiring managing agents, approval, contract negotiations, random quality checks, perceived liability risks	10% (lighting) and 30% (insulation) of total investment costs.
ESCOs in the USA[d]	Prospecting, proposal, project identification, M&V	20-40% of total project costs
Procurement strategies for utilities in Maryland, USA[e]	Costs for bid preparation, credit guarantees, utility account management, and legal and regulatory affairs	5-10% of total contract costs

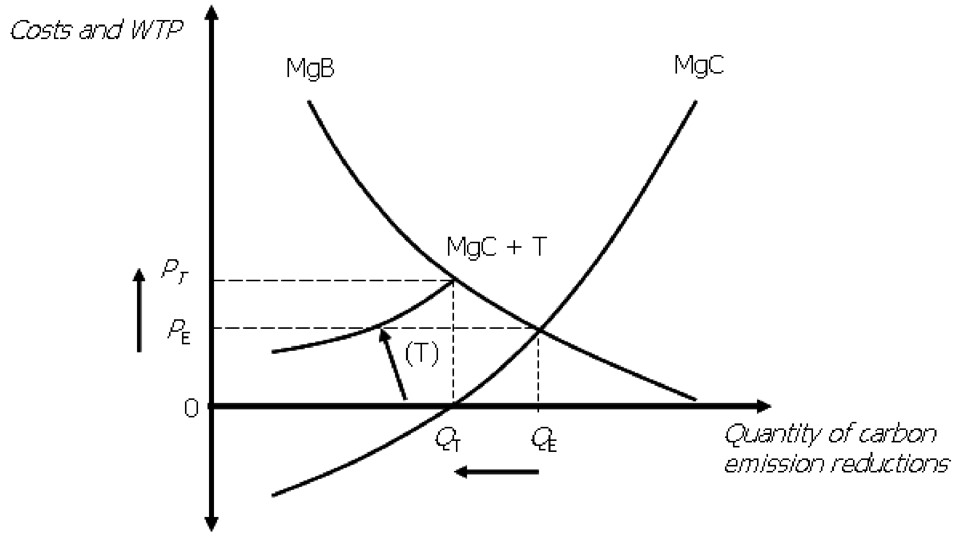
Sources: [a]Joskow and Marron (1992); [b]Mundaca and Neij (2006); [c]Mundaca (2007b); [d]Easton Consultants (1999); [e]Wallach et al. (2008).

Table 2 Estimated aggregated scale of transaction costs related to renewable energy technologies

Case study	Nature of TCs	Scale of TCs	
EU market for green electricity[a]	Search and pre-feasibility, negotiation and development, approval and administrative procedures, monitoring (accounting and verification), enforcement, and adjustment costs	13.5% of total investment costs	
Tradable Green Certificate scheme in the Netherlands[b]	Costs undertaken by obligated parties beyond costs of meeting the obligation itself	2.5% of total activity compliance costs	Battjes et al. (2000 in Oikonomou and Mundaca, 2008)
Tradable Green Certificate scheme in Sweden[c]	Costs to handle quota obligation on behalf of end-users	18% of the value of a certificate 15-24% of average price-cost margin of a certificate	
Renewable Portfolio Standard in Texas, USA[d])	Search, negotiation and contracting, metering/auditing/billing, paying/monitoring, calculation of obligated amounts, submission of certificates, monitoring, enforcing, issuing certificates, reporting and adapting, application for certificates	2.9 % of the value of the RE electricity	
Feed-in-tariff in Germany[d]	Direct TCs (excluding indirect TCs related to governance): negotiation and contracting of secondary duties, capacity calculation, metering, billing, paying, auditing, accounting, biannual report and clearance.	1.3% of the value of the RE electricity	
Sugar cane for electricity generation in Brazil[e]	Search and information, risks related to non-compliance (fines), negotiation and renegotiation of contracts, insurance, compliance	N/a	

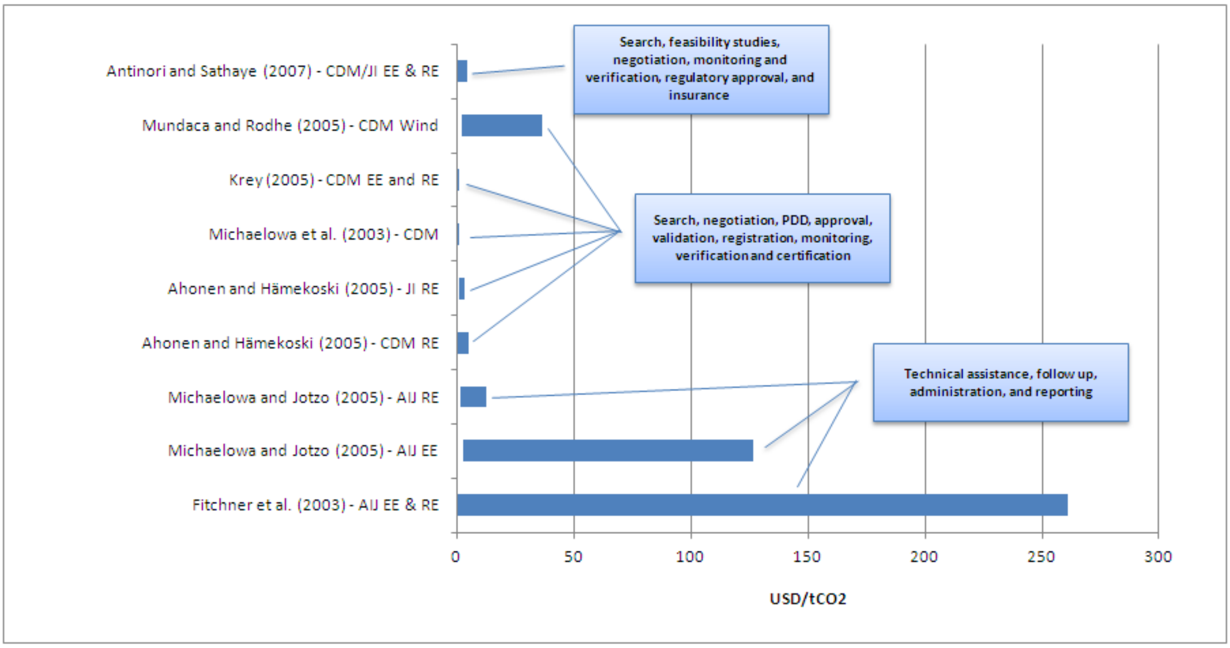
Sources: [a]Skytte et al. (2003); [b]Battjes et al. (2000); [c] For value of certificate, Kåberger et al. (2004). For average price-cost margin, Nilsson and Sundqvist (2007); [d]Langniss (2003); [e]Nagaoka (2002).

Figure 1 Impact of (decreasing) transaction costs on carbon emission reductions



Notes: *x*-axis represents the quantity of carbon emission reductions; *y*-axis indicates monetary terms (costs and WTP); *MgC* is a carbon abatement cost curve and represents the supply of carbon emissions reductions at different marginal costs. These costs are a function of different LCTs and the resulting extra carbon reduction units; *MgB* depicts the private (i.e. not social) marginal benefits and represents the willingness to pay (WTP) for extra units of carbon emissions reductions.

Figure 2 Identified scales (lower and upper values) and key sources of TCs for CDM/JI low-carbon technology projects



Notes: CDM = Clean Development Mechanism; JI = Joint Implementation; EE = energy efficiency; RE = renewable energy; AIJ =Activities Implemented Jointly.