

Transaction Costs of Low-Carbon Technologies and Policies

The Diverging Literature

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Abstract

Transaction costs are major challenge to moving forward toward low-carbon economic growth, as new technologies or policies tend to have higher transaction costs compared with those in the business as usual situation. However, neither a well-developed theoretical foundation nor a consensus interpretation is available for those transaction costs in the existing literature. The definitions and therefore the estimations of transaction costs vary across existing studies. The wide variations in the estimates could be attributed to several factors such as the

very definitions and scope of transaction costs considered in the studies, the methodology for quantifying these costs, the type and size of low-carbon technologies, and complexities involved in the transactions. Nevertheless, the existing literature converges on addressing market failures, such as lack of information, in developing regulatory and institutional capacity to enhance private sector confidence in energy efficiency business as a key means to help reduce the transaction costs of low-carbon technologies.

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1. Introduction

Transaction costs (TCs) can be broadly defined as costs not directly involved in the production of goods or services but that arise from transactions that are essential for realising the trading of those goods and services as such (Coase, 1960). Low-carbon technologies are, in general, more expensive than conventional ones. Even if they are economically attractive, as with for example net saving of electricity bills through the use of more energy efficient appliances, the economic benefits may be outweighed by, for instance, the costs of searching and assessing information about low-carbon technologies, the costs of making decisions on optimal selection of technologies, and the costs of validation, monitoring and verification of emission reductions. As technology costs for low-carbon technologies are higher, policy instruments are needed to deploy the technologies; but the results of policy will be limited by transactions costs. Reduction of transaction costs is a critical condition for increased deployment of low-carbon technologies.

Conventional top-down and bottom-up modelling of low-carbon technologies and policies have tended to assume that transactions required to implement low-carbon technologies are costless (see e.g. Hourcade et al., 1995; 2006; Worrell et al., 2004). The outcome is that modelling results might underestimate the costs of reducing GHG emissions. For instance, many bottom-up modelling studies, such as World Bank (2009), World Bank (2010), McKinsey, (2009) estimate that most energy efficiency measures could result negative net costs to investors (i.e., energy savings outweigh implementation costs). McKinsey (2009), particularly, estimates that energy efficiency improvements can reduce up to 14 GtCO₂ per year approximately – or nearly 40% of the global GHG abatement potential by 2030 – at negative net costs for investors. However, these studies overlook long-standing critiques of conventional bottom-up models, in particular the treatment of market and behavioural failures² that impede the realization of such potentials.³ These studies consider only the market costs of technologies (i.e., investment for purchasing and installation of technologies, expenditure on operation and maintenance of these technologies for their economic life).

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² Market failures are hereby defined as flaws in the market that do not allow efficient or optimal allocation of goods and services (e.g. negative externalities not reflected in energy prices, asymmetric and imperfect information about the performance and risks of mitigation technologies). Behavioural failures are defined as decision-making actions by firms and consumers that lead to apparent divergences from utility/profit maximization goals.

³ This is also termed an '*energy efficiency gap*' which is generally used to describe the slow diffusion of profitable efficient technologies that fail to achieve market success (Jaffe and Stavins, 1994).

Much of the debate on energy efficient technologies is related to the treatment of market and behavioural failures (cf. Hourcade et al., 2006).⁴ Whereas there has been debate on whether TCs are, or are not, an additional source of market failure – and therefore whether governmental intervention is or is not required (c.f. Jaffe and Stavins, 1994; Howarth and Sanstad, 1995) – there is consensus that these costs do exist in energy technology markets (see e.g. Joskow, 1991; Ostertag, 1999). As a whole, it is argued that TCs are a significant but missing aspect that tends to overestimate GHG emission reduction potentials (see e.g. Fitchner et al., 2003; Michaelowa et al., 2003). The analysis of TCs can better assist comparative policy studies; improve the design implementation of policies; and support evaluation studies to boost the performance of policies (McCann et al., 2005).

Against this background, the objective of this paper is to provide a comprehensive review of empirical studies addressing TCs analysis that focus on energy efficiency (EE) technologies, renewable energy (RE) technologies, and carbon markets. All literature related to both the theoretical and empirical aspects was carefully reviewed. Gray literature (e.g., technical reports, unpublished draft papers and working papers) has also been included. The study first examined the theoretical debate on TCs, such as raised by Jaffe and Stavins (1994), Stavins (1995) and Howarth and Sanstad (1995) and attempt to clarify TCs affecting low-carbon technologies. Our review departs from industrial organisation studies that build on the theory of the firm in analysing the structure of, and boundaries between, firms and markets (see e.g. Williamson, 1981; Grossman and Hart, 1986; Hart and Moore, 1990).

TCs occur at different stages in a project/activity cycle, such as planning, implementation, monitoring and results verification and product certification and trading. At all levels, it is sometimes difficult to separate or draw a clear line of TCs along the project cycle (e.g. search for information costs might be applicable throughout the entire project cycle). The contributions of both endogenous and exogenous factors under these stages are discussed in each of the focus areas. The reasons for the wider variations in the estimations of TCs in the existing literature are also investigated.

2. Conceptual framework

2.1. Key initial theoretical considerations

Leon Walras built a model of market equilibrium according to which the pursuit of self-interest in a competitive market will automatically lead to the maximization of the society's total utility. In 1937, in the famous paper “*The Nature of the Firm*”, Ronald Coase asserted that there is however a cost for running the economic system, that is a cost for the actual process of exchange of a good or a service performed by economic agents to occur (Coase, 1937). He characterized such an exchange in terms of a transfer of property rights. The more business activities develop, the more the number of transactions increases and the more complex the nature of transactions becomes. Several years later in his paper “*The Problem of Social Cost*”, Coase (1960) attributes the function (or reason for the existence) of firms to the superiority in

⁴ Seminal contributions in this area are contained in the special issue of Energy Policy on Markets for Energy Efficiency (see Huntington et al., 1994).

handling production. Following Coase's seminal papers, two postulates emerged: first, institutions play a role in the economic activity, and second, there are costs in realizing market transactions.

Firms, according to Coase (1960), Chandler (1962) and later Williamson (e.g. 1981; 2010), are the reason behind the existence of TCs.⁵ Analyzing the hierarchical forms of business organisation (e.g. the evolution of the large multifunctional enterprise and the divisionalization of the firms), Chandler (1962) in his groundbreaking work “Strategy and Structure”, formulated the organizational forms of firms allowing to understand and apply the concept of TCs to the (institutional) economic system. Combining primarily economics and organization theory, Williamson (1971, 1979, 1993, 2010) has dealt with the problem of what explains the boundaries of the firm. The “transactions, which differ in their attributes, are aligned with governance structures which differ in their costs and competences, so as to affect a transaction cost economizing result” (Williamson, 1998, p.37). Contracting between firms echoes what Williamson (1993) calls the fundamental transformation, that is a situation moving from an *ex ante* competitive situation to an *ex post* contracting situation between two entities that recognize each other's identity. Within the firm, vertical integration (also referred to as “make or buy” decision) represents the paradigm transaction because through “unified ownership”, it facilitates contractualization (Williamson, 2007).

Albeit often attributed to Coase, institutional economics was initiated by John R. Commons and the German Historical School (Thorstein Veblen). Commons (1934) established the transaction as being the basic unit of analysis to study economic organization, which became the main focus of the New Institutional Economics (NIE) school of thought. The NIE focuses on how decisions and transactions made by market agents are frequently based on imperfect information, and also on how institutional frameworks influence the behavior of these agents (Ménard, 2004). The role of institutions in regulating exchanges is central to both Williamson's (1981) and North's (1990) approaches to TC analysis, but at different levels. Williamson (1981) considers that the role of institutions and their arrangement is to minimize TCs, while North (1990) points out the existence of inefficient institutions.

In a macro-economic point of view, North (1990) states that transacting is costly because agents when exchanging have to determine the socio-political value of the assets on which the economy is based. In order to exchange, agents have to measure, monitor and enforce to determine the attributed values of a potential agreement. In turn, measurement, monitoring and enforcement activities generate a cost. North (1990) argues that because measuring the valued attributes in full is costly, the opportunity costs for securing wealth by devoting resources to getting more information is present at all times. Furthermore, agents incur different costs for acquiring information and value an exchange of property rights differently. However, even though political institutions can contribute to facilitate bargaining between agents, they do not necessarily lead to an efficient allocation of property rights in economic terms. North's TC analysis

⁵ For a recent review of transaction cost economics, see Williamson (2010).

has been described as the “*visible hand*” approach to institutional economics (Aoki, 2001).

From a microeconomic standpoint, Williamson's TC analysis is a theory of contracts defined as “the institutional framework within which the integrity of a transaction is defined” (Williamson, 1979, p. 235). Market agents have a bounded rationality and are prone to opportunistic behavior, defined by Williamson as “self-interest seeking with guile” (Williamson, 1981, p. 1545). TC analysis operates at the individual level depending on the behavior of agents engaged in contracting transactions. While in the neoclassical theory, the firm searching to maximize its profit represents the structure of governance and firms and markets are considered as two separate entities, Williamson's governance structure belongs to the economics of organization and alternates between markets and hierarchy. According to the framework developed by Williamson (1998), the NIE operates at two interconnected levels. TC analysis materializes in the level of the institutions of governance qualified as the “play of the game”, where agents proceed with transactions on the market based on the higher level of the institutional environment (politics, legal regulations and bureaucracy) which set the “rules of the game”. In order to identify the level of complexity of a transaction, and as a consequence whether a transaction should be done within a firm or on the market, Williamson (2007) established three determinants: (1) the specificity of investments, e.g. the possible redeployment of an investment will determine the level of its specificity; (2) the frequency of the transactions; and (3) the uncertainty of transactions (it is impossible to know in advance future contingencies of a contract).

Based on Coase's core ideas, Alchian and Demsetz (1972) also developed further the reasons for the existence of firms. A firm is a contractual structure between the firm's owner (called the “central agent”) and input owners subject to continuous negotiation ensuring an efficient organization of team production. The firm serves as a “device” for strengthening competition among the input of resources and rewarding inputs efficiently. In that sense, the firm is assimilated to a privately owned market that is more apt at organizing and influencing the use of resources. Williamson (1971) considers that in order to control or reduce TCs, firms represents a more attractive and effective structure compared with exchanging on markets as such when it comes to: (1) bargaining, (2) enforcing and rewarding, (3) resolving conflicts through fiat, and (4) exchanging information.

2.2. Related analytical work and conceptual divergences

In its numerous empirical applications, conceptual approaches and views on TC analysis vary and several challenges in interpreting results are regularly pointed out (please see for example, Coggan et al. 2010; McCan, 2013; Pannell et al. 2013). At the general level, it is argued that much more clarification and further research is needed to address the fundamental issues related to the typology, chronology, and quantification methods on transaction costs measurement (McCann et al., 2005). Hahn and Hester (1989) argue that, while producing “elegant” results, positive and normative theory related to instruments for environmental markets, are “overly simplistic” and not immediately applicable to the reality of issues actually encountered. While a large part of the research conducted is empirical, Macher and Richman (2008) recommend more efforts be put on the formalization of a solid theoretical foundation that can

allow greater precision regarding key concepts, improve theory's existing forecasts, as well as develop and test new hypotheses and empirical implications.

Joskow (1991) stresses that TC analysis needs rigorous mathematical foundations. The reviewed literature acknowledges that there is a lack of precision and testing for transaction variables in empirical studies, in particular asset specificity (Macher and Richman, 2008). Values or parameters are often taken from secondary sources which make the interpretation of results difficult. In addition, one can also observe that interaction effects among and between TCs variables is also latent thus ignoring important additional factors that may affect a contract (Macher and Richman, 2008). Identifying the nature of relationships among costs is also a complex issue. For instance, production costs and governance costs are not always independent of each other and may depend on organization and technology (Langniss, 2003; Milgrom and Roberts, 1992). Costs can be in some cases attributed to the technology and not to the transaction itself (Langniss, 2003). Bardhan (1989) argues that the postulates according to which institutions affects transactions to make them cost-effective are not clear. Firstly, there is the problem of collective action, which translates into the difficulty for parties to share the benefits coming from institutional change and the problem of free-riders, that is, generally speaking, agents who receive benefits or use resources without bearing any costs. Secondly, institutions do not necessarily lead to optimality. Dysfunctional institutions can remain in place for a long time creating lock-in situations and self-reinforcing mechanisms. Grossman and Hart (1986) have criticised the imprecision of transaction costs analysis and have developed the theory of incomplete contracts in which they define ownership as the being the residual rights of control, and vertical integration as being the acquisition of those residual rights.⁶ In all, and despite the fact that formal research on TCs has taken form in the past decades, Williamson (2010) argues that research in this area face an interesting but still challenging future.

The discrepancies observed above have an impact on the conceptual choices that frame empirical studies. We find across the literature numerous and sometimes competing definitions of TCs. For instance, Arrow (1969) qualifies TCs as the cost of running the economic system by attributing market failures to TCs: “market failure is not absolute; it is better to consider a broader category, that of TCs which in general impede and in particular cases block the formation of market”. Eggertsson (1990) attributes TCs to the exchange of ownership rights to economic assets between individuals and the enforcement of their exclusive rights. Other definitions include policy aspects: Gordon (1994) describes TCs as the cost of organizing and participating in market or implementing a government policy. According to Kuperan et al., (1998), for the purpose to analysing TCs between different policy arrangements, TCs can be categorized in information costs, collective decision-making costs, and collective operational costs. Allen (1991, p. 3) proposes a more complete definition: “transaction costs are the resources used to establish and maintain property rights. They include the resources used to protect

⁶ Vertical integration is a way to sustain some of the measurements costs of exchanging, as well as trust, brand name and the repetition of purchase (Barzel, 1982).

and capture (appropriate without permission) property rights, plus any deadweight costs that result from potential or real protecting and capturing”. With regards to the composition of TCs, some authors assimilate transaction and administrative costs (Stiglitz, 1986; Joskow and Marron, 1992).

For the particular case of low-carbon technologies, different conceptual choices are identified. For instance, Ostertag (1999, p. 2) considers 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”, including the costs to determine which technology is the most cost-efficient. This would lead to including costs spent also for measures not implemented since in most of the cases, only costs related to an implemented measure are accounted for. Mundaca (2007a, 2007b) builds upon the concept developed by Matthews (1986) to identify sources of TCs associated with ex-ante and ex-post activities for arranging, monitoring and enforcing a contract. Langniss (2003) in his comparative study of the nature and scale of TCs resulting from the German Renewable Energy Act (EEG) and the Renewable Portfolio Scheme (RPS) in Texas, includes not only the costs related to the activities directly attributed to the implementation of the RE scheme but also political transaction costs related to regulations.

Classifications of TCs also vary greatly across the literature. Skytte et al. (2003) classify TCs across pre-implementation and production phase, while define costs arising from the implementation phase of a project within the European Union as opportunity costs. The authors argue that in this case, opportunity costs are determined by the construction and commissioning time, that is, the time an investor is waiting from obtaining the building permit to selling the electricity. The literature covering the Kyoto Protocol mechanism however include the implementation phase of a project as part of the transaction costs (see e.g. Michaelowa et al., 2003; Krey, 2005; Mundaca and Rodhe, 2005). TCs are qualified as on-going or one-time costs (MRC, 2004), or also variable or fixed (Michaelowa et al., 2003). McCann et al. (2005) also raise a question about the difference in scale and methodologies (including data availability) for measuring TCs in different contexts (i.e. less developed and developed countries). Degla (2012) has summarized definitions of transaction costs used in several studies since Coase (1937).

In order to shed more light on the definition or interpretation of TCs, below we present a few examples from recent literature (Table 1). As can be seen from the table the elements of TCs could be significantly different across the sectors. For example, in the natural resources and forestry sector, property right is the key issue. It is therefore, costs caused by ill-defined property rights are the main elements of TCs besides negotiation and enforcement costs. On other hand, for energy sectors (e.g., renewable energy and energy efficiency projects), informational, technical, financial and institutional barriers constitute major portion of TCs. Moreover, TCs could differ across type of activities. TCs related to deployment of new and emerging technologies (e.g., renewable energy, energy efficiency) would be much different from that involved with marketing of conventional agriculture products (e.g., potato and wheat). The latter is related to transaction or exchange and are the basis for the traditional definition of TCs. The former can be considered as new elements of TCs and, in fact, there does not exist any

guidance in existing literature whether they should be termed as TCs. The TCs related to carbon market under the Kyoto Protocol or any other voluntary carbon markets are additional to the new TC elements related to barriers to technology deployment and traditional TC elements associated with transactions and exchanges. Thus, if TCs related to low-carbon technologies and policies are to be covered, the traditional of definitions of TCs need an expansion.

Table 1: Examples of Definitions and Interpretations of TCs in Recent Literature in Various Sectors

Sector	Area	Definition/interpretation	Source
Natural resources and forestry	Community based natural resource management	Costs associated with negotiation, attendance at community meetings, monitoring activities, resolution of conflicts, and enforcement of property rights to natural resources	Ray and Bhattacharya (2011)
	Reducing Emissions from Deforestation and Forest Degradation (REDD) programs	Property right costs (i.e., costs related to sorting out of property rights between forest owners and users), negotiation costs (i.e., the negotiation of contracts with landowners); monitoring and verification costs (i.e., the monitoring and verification of outcomes); and enforcement costs (i.e., the enforcement of contracts if the parties do not fulfil their obligations)	Alston and Andersson (2011)
	Land-use change and forestry	Cost associated with search and negotiation, approval, project management, monitoring, enforcement and insurance	Cacho et al. (2013)
Agriculture	Marketing of agricultural commodities, such as banana, potato and cashew nuts	Information and search costs (e.g., searching market price information, price uncertainty); negotiation and bargaining costs (e.g., time spent transacting with private traders, transaction delay costs, transportation costs); monitoring and enforcement costs (e.g., speed of payment, trustworthiness of traders, contract enforcement); socioeconomic costs (e.g., availability of credit, farmers' experience)	Woldie and Nuppenau (2012); Degla (2012); Escobal and Caverro (2012)
	Reducing dry land salinity, conserving of biological diversity and improving water quality	Costs that have been incurred by a team of collaborators working to address the identified problems. It includes: getting public comment on existing programmes; presentations to various audiences; research to better understand neglected issue; pilot testing of the decision tools; training programmes and user support; participation in committees, reviews and inquiries; and broad communication through web sites and publications.	Pannell et al. (2013)
Energy	Renewable energy	Costs related to governance structure shaping transactions between the public authority (government or a regulator), the renewable energy producers and the obligated buyers	Finon and Perez (2007) Perez and Ramos-Real

			(2010)
	Energy efficiency	Costs related to all types of barriers (e.g., information, financial, technical, institutional) to the deployment of energy efficiency activities	Sarkar and Singh (2010)
	Greenhouse gas policies in the Australian transport energy sector	Research and information costs (inquiring and seeking clarification about the policy measure, conducting public education, preparing application and guidelines, searching for information about buyers and sellers); enactment costs associated with legislation, implementation costs including the costs of designing permit allocation system, defining trading rules, and regulatory delay; administration costs (communication and assistance, giving information about a policy, assessing applications, performing auditing tasks, providing permit price forecasts, keeping records, consultation processes, developing required resources such as training agency staff for new tasks, purchasing and installing relevant equipment); contracting/trading costs (interviews and supplementary information and negotiating over prices to enter into a contract, organising purchase or sale of permits, identifying and matching potential trading partners and fulfilling brokerage needs); monitoring/detection costs and enforcement costs involving time and money in enforcing compliance through the legal system	Ofei-Mensah and Bennett (2013)
All Sector	Kyoto market mechanisms (Clean Development Mechanism and Joint Implementation)	Relevant TCs identifies in sectors above plus costs of project validation and registration, monitoring, emission reduction verification and certification	Michaelowa et al. (2003); Krey (2005)

2.3. Chosen concept and taxonomy of transaction costs for low-carbon technologies

In this paper, TCs are understood to represent the costs for (technological) entities to conduct transactions: ex-ante costs of negotiating and writing and an ex-post costs of executing, policing and enforcing (Williamson, 1981). This paper categorically excludes costs of some barriers to clean energy technologies, as well as costs associated with behavioral attributes of consumers. These include higher interest rates perceived by commercial banks due to higher risks associated with clean energy technologies; consumers' reluctance to adopt energy efficient technologies as they value the current capital costs much high than the benefits from energy savings in future; and higher-income consumers' indifference to monitoring their energy expenditures because they do not care much about energy expenditure as it is small compared to other expenditure items. Most existing literature on transaction costs does not include

these types of barriers as part of transaction costs. There exists a separate stream of rich literature on barriers to energy efficient, and new and emerging energy technologies.⁷

Following on this, Matthews (1986, p. 906) also introduces the ex-ante and ex-post boundaries by defining TCs as “the costs of arranging a contract ex-ante and monitoring and enforcing it ex-post, as opposed to production costs.” For the purpose of our study this definition is convenient as it encompasses the basis of many empirical studies reviewed. It is broad enough to allow more refined delimitations according to the scope of empirical studies conducted while providing a useful separation of the realization of the transaction occurring as an agreement or a contract between two parties. The chosen definition adheres to the ex-ante and ex-post costs proposed in TC analysis in which an optimal institutional arrangement would succeed at reducing ex-post hazards of opportunism through ex-ante choice of a governance structure (cf. Williamson, 1998).

Regarding the taxonomy of TCs, we use the following conceptual classification to frame and guide our review.⁸

- *Search for information costs.* The implementation of processes from the demand side incurs TCs related to the search and processing of information. Sioshansi (1991) states that consumers face high TCs in order to obtain timely and appropriate information. Before entering into an agreement, implementing an energy efficiency measure (e.g. building insulation) (Mundaca, 2007), buying a new electrical appliance (Björkqvist and Wene, 1993), trading permits or allocations (e.g. Green Certificates, White Certificates, EU Emissions Trading Scheme), or redeeming credits to mitigate Greenhouse Gases (GHG) emissions (e.g. Certified Emissions Reductions (CERs) under the Kyoto Protocol's Clean Development Mechanism (CDM) (Michaelowa and Jotzo, 2005), economic agents or parties⁹ have first to search for information in order to (1) decide whether or not the transaction is relevant towards the expected outcome (2) possibly select one option amongst several and (3) if conditions are met, establish the best conditions for it based on the information. The type of information sought can be related to the parties involved (e.g. trading partners), the market, the technology, or the type of investments. Information can be asymmetrical: one party may hold more information than another or both parties may have information but different information. Information also includes information on formal and informal rules towards social, economic and political integration restricting parties' actions. The costs to obtain and process information vary. For instance, in the case study conducted by Sathaye and Murtishaw (2004), consumers searching for information and vendors providing information to consumers generate TCs in the fact that vendors have to spend some of their working time to

⁷ Interested readers could refer to some existing literature such as Sorrell et al. (2004) and Thollander and Palm (2013).

⁸ McCan (2013) also discusses various sources of TCs.

⁹ “Economic Agents” or “Parties” refer to the nature of the transactors: government bodies, firms, consumers/households, public organizations, etc.

inform customers about the product. Parties will also incur costs in searching for potential partners, secure funding, and establish a preliminary budget (Skytte et al., 2003). In the case of the Kyoto Protocol mechanisms, the definition of a baseline in order to determine the amount of avoided GHG emissions of a given project to be developed is a significant source of TCs. Similarly, the costs related to the Project Design Document (PDD) include baseline costs which take the form of time and resources spent for data gathering, analysis, processing and documentation, environmental impact documentation costs, stakeholder consultation costs, etc. (Krey, 2005).

- *Decision making costs.* Once the information has been found and processed, agents have to make a decision on whether to proceed with the transaction and possibly will have to choose between different options (Björkqvist and Wene, 1993). Again, the literature stresses that uncertainty associated to low-carbon technologies tends to put a higher decision-making burden as compared to proven technologies (Hein and Blok, 1995).
- *Negotiation costs.* Negotiation occurs as to define the terms of the agreement. It also encompasses the process in which parties agree on the terms of the contract or the project to be implemented. Negotiation costs include the time spent for the participants to negotiate, the subcontracting of consultants or lawyers' fees. For instance in the case of the first phase of the Energy Efficiency Commitment (EEC) in Great Britain, parties engaged into energy efficiency measures hired third parties to handle their obligation or appointed contractors to implement insulation measures (cf. Mundaca, 2007b).
- *Approval and certification costs.* These are costs generated when the transaction needs to be approved by an institutional body prior to its implementation. For instance, a project developer of a CDM will incur costs to have the host country approve the project through meetings and presentations. The CDM Executive Board also has to approve the project prior to its implementation. Especially in trading schemes, such costs also result from the requirement for the project developer to have the outcome of the transaction certified, such as CERs certified in order to deduct them from its GHG emissions and meet the targets. In the case of white and green certificates, there are redemption costs resulting from the necessity to redeem the certificates to prove that targets are being met. Under the first phase of the Energy Efficiency Commitment in Great Britain (2002-2005), TCs are related to the person-to-person costs of researching and assessing information during the quarterly process of declaring savings to the authority (Mundaca, 2007).
- *Monitoring and verification costs.* After the implementation of an energy measure, monitoring needs to happen in order to assess the economic effectiveness of the transaction. These types of costs occur as the parties need to observe the transaction as it happens and in a way that adheres to the agreement (Dudek and Wiener, 1996). In the case of several project-based mechanisms (e.g. Clean Development Mechanism (CDM) or Tradable Green Certificates (TGC) schemes), these

costs arise from the purchase and installation of equipments required for the monitoring, data processing, random checks and archival processes. They can be initial and one-time costs, such as the purchase of the equipment and recurrent costs depending on the frequency in which the verification take place (Krey, 2005). Ostertag (1999) and Langniss (2003) characterize these costs as “metering costs”.

- *Enforcement and compliance costs.* In case of non-compliance (e.g. when a given mandatory target is not met by subject parties), a party may decide to take measures to put *pressure or act upon the failing party* in order to rectify the issue, to renegotiate or to cancel the contract or agreement (cf. Skytte et al., 2003; Langniss, 2003). These costs can take the form of time and resources needed to develop an enforcement plan and communicate with the failing parties, or of the hiring of a lawyer.
- *Trading costs* occur on trading markets when quotas, allocations or certificates are traded. A party which does not fulfill its emissions obligations can buy quotas, permits or credits on the market, at the market price. On the contrary, a party that has exceeded its obligations can sell some of its emissions. This trading can be done internally within a company or through trading agents or brokers who do take a fee when performing the transaction (cf. Skytte et al., 2003; Mundaca, 2007a, 2007b).

3. Transaction costs related to energy efficiency technologies

This section presents the nature and scale (either disaggregated or aggregated) of TCs related to the planning, implementation, and measurement and verification (M&V) phases of EE technologies outside carbon markets. Depending on the policy instruments under analysis, we also examine the trading of energy savings. This is because we also give special attention to the analysis of TCs resulting from policy instruments such as Tradable ‘White Certificate’ schemes that encourage GHG emission reductions through the promotion of EE technologies.

3.1. Nature of transaction costs for energy efficiency technologies

Transaction cost related to planning. Focusing on the penetration of Compact Fluorescent Lamps (CFLs) and washing machines on the Californian market, Sathaye and Murtishaw (2004) found that, among several factors e.g. product availability and lifetime uncertainty, the nature of TCs is related to information processes that arise from the costs to acquire, assess and use information about the product. For instance, ‘product information cost’ refers to the cost to make consumer aware about potential energy savings and the cost for the consumer to assess with exactitude the amount of savings. ‘Vendor information cost’ refers to the cost for the vendor to inform the client. ‘Consumer preference’ refers to

the outcomes resulting from consumers' limited cognitive ability in assessing and gathering information.¹⁰ Studying large energy intensive firms in the Netherlands, Hein and Block (1995) found that the main sources of TCs are those related to information gathering and its due assessment. Analyzing the 'Free-of-Charge-Energy-Audit' (FCEA)¹¹ in Denmark in the context of the Tradable White Certificate (TWC) schemes, Mundaca and Neij, (2006a) found that the search for information was the most relevant source of TCs for electricity companies. As such, the information costs for electricity companies relate to looking for customers demanding energy audits, as well as information required by the regulatory framework to check the progress of implementation. Auditing small and medium companies also proves to be more costly than auditing large companies (Mundaca and Neij, 2006a). With a specific focus on the British TWC scheme (called the 'Energy Efficiency Commitment' [EEC] at that time¹²), Mundaca (2007b) also found that information costs occurring the planning phase was an important source of TCs. The reason for such costs is to find out what measures to take and what customers would be likely to implement them. Subject parties often needed to persuade customers to effectively implement those measures. These activities (e.g. awareness rising campaigns, free provision of CFL) were sometimes subcontracted and conducted together with local authorities, charity organizations or consultants. In addition, it is also found that person-to-person costs for researching and assessing information to obtain the due approval from the authority are also sources of TCs related to search for information (Mundaca, 2007b).

Transaction costs related to implementation. Björkqvist and Wene (1993) found that time dedicated to decision-making processes for adopting (or not) efficient technologies are significant source of TCs for Swedish families when improving the energy efficiency of their heating system (e.g. time devoted to analyze and reduce uncertainty about performance of technologies). Hein and Block (1995) focus on costs related to decision making by energy managers. They note that these costs vary depending on the approval process in place and also the human and embedded financial resources associated with the decision-making process before agreement among parties (e.g. whether an investment is to be approved by a manager or CEO affects TCs differently). For the FCEA in Denmark, Mundaca (2007a) identified that TCs are also related to contacts and contracts negotiation during the development of the energy saving plan. These costs originate from the interaction between Operations and Maintenance (O&M) teams and manufacturers. For a complete elaboration of this energy saving plan, electricity companies need to

¹⁰ Each factor is weighted against the others and the cumulative effect in terms of Cost Conserved Energy (CCE) curves showing cumulatively effects on the penetration of the stock (or the number of adopters) and the potential of GHG savings.

¹¹ Under the FCEA, electricity grid companies are obliged to conduct audits in organizations that consume more than 20MWh annually. The audits were financed through electricity bills by the end users. within the FCEA: 1) a general overview, 2) analysis of findings, 3) development of saving plan, 4) follow-up of audit, 5) report to the audited company, and 6) report to a common database. In 2003, the expenditures of the program amounted to 22 million Euros of which more than half were spent on energy savings measures (ELFOR, 2004; Mundaca & Neij, 2006a).

¹² The EEC (now closed and replaced by the 'Carbon Emissions Reduction Target' scheme) imposed an energy saving quota on energy suppliers to be met in the residential sector. The scheme allowed participants to trade certified energy savings as a mean of cost-effectively reaching energy efficiency targets set up by the government.

interact with O&M teams and manufacturers or dealers of equipment to be potentially implemented. Electricity companies perceive their role as facilitators, assisting the audited companies during the decision-making process for implementing the suggested energy efficiency measures. For the British TWC scheme, it is identified that energy suppliers conducted the preparation of documents to gain approval from the authority. Having the correct information was critical because endorsement by the authority was needed before implementation could take place. Furthermore, the contract negotiation often involves third parties such as consultants or retailers. Hiring consultants was important to, for instance, facilitate arrangements between suppliers and local authorities and/or guide on the type of measures to be implemented and facilitate understanding of the regulatory framework (Mundaca, 2007b). Energy suppliers also negotiated contracts with insulation contractors. This aspect was highly critical because insulation measures (100% sub-contracted) delivered the most cost-effective energy savings, representing nearly 60% of total delivered energy savings (Mundaca, 2007b, p. 4344). The study carried out by Ostertag (1999) also identified TCs in relation to contract negotiation, in particular in relation to the so-called “hold-up problem” that can arise in bilateral agreements. In this case, and due to the specificity of an investment, which might not be implemented in another context, a contractual agreement between a supplier and a manufacturer create a bargaining power for one of the contracted parties. Besides, not all terms of a contract might be known or fully appreciated in advance. Therefore in a contractual agreement, the cooperation might not be optimal, generating higher costs or reducing profits.¹³

Transaction costs related to monitoring and verification (M&V) processes. Joskow and Marron (1992) studied electricity conservation programmes, run by utilities, through subsidies to customers for efficient technologies. While they do not evaluate transaction costs explicitly, they do account for “administrative costs”, including the monitoring and evaluation as well as the promotion and delivery of conservation measures.¹⁴ Analyzing heat suppliers, Ostertag (1999) identifies sources of TCs in relation to personnel required for supervision or maintenance induced by a new energy installation, as such, M&V costs are part of the “base price”.¹⁵ Other sources of TCs such as the costs to be connected to the grid, or the necessity to rebuild a chimney due to different technical settings of a more energy efficient boiler newly installed are also possible to identify. Regarding the British TWC scheme, the main source of TCs is associated with random quality checks activities performed by suppliers in relation to installation and customer satisfaction. This is driven by the fact that once measures were implemented, suppliers were required to monitor a proportion of all installations with respect to the exact number of measures

¹³ The “hold-up” problem can also prevent the conclusion of agreements. Notice that this issue has been developed by Klein et al. (1978) and is a key concept in explaining the boundaries of the firms (Holmström and Roberts, 1998).

¹⁴ Note that Joskow and Marron (1992) present in details the limitations of their studies and how they think it impacts the interpretation of the results. This provides an interesting insight on factors to take into account when performing such studies for which data collection and methods presents serious limitations.

¹⁵ Ostertag (1999) distinguishes transaction costs as “base price” which include administrative costs including contract negotiation, information collection, monitoring of new installation, investment costs, fuel and electricity costs, costs for repair, maintenance, insurance and rent, “operating price” which represent fuel delivery costs, electricity costs and “metering prices” which are costs for measurement and control of emissions, cost for standardization of metering equipment.

implemented (Mundaca, 2007b). Suppliers deployed a variety of follow-up activities (e.g. telephone interviews, questionnaires, and random home visits). Furthermore, once technologies are implemented, TCs also arise from researching and assessing information activities related to declaring savings levels to the authorities. Note that under the EEC there was no actual M&V of energy savings and thus related TCs. This is because energy savings, heavily associated with well-known technologies in the residential sector (e.g. CFL) were estimated on ex-ante basis (Mundaca, 2007b).

Transaction costs related to trading. For this particular phase of EE technology implementation, the only case that we identify is related to British TWC scheme, which allows energy suppliers to trade energy savings (and allocated quotas) in order to facilitate the cost-effective achievement of energy savings. While actual TCs affecting the trading of savings or quotas were not identified, Mundaca (2007b) identified that *perceived* TCs encouraged a low level of trading among subject participants. Perceived TCs were associated with two particular sources, namely contract negotiation and liability risks. Results reveal that suppliers prevented themselves from trading because they could disclose strategically sensitive information (e.g. compliance costs) to a buyer/seller of energy savings who was actually also a market competitor. This could have negative strategic and commercial effects. In addition, trading was negatively affected also because suppliers considered it too risky to embark on trading without being sure who was legally responsible should the implementation of measures not go according to plan.

3.2. Estimated scale of transaction costs for energy efficiency technologies

Due to different conceptual and methodological aspects, we stress that the reviewed case studies with regards to the quantification of TCs differ – sometimes to a large extent. Some studies focuses on the quantification of specific costs, while others aggregated them.

Disaggregated estimates. Sathaye and Murtishaw (2004) focuses on energy efficiency options and their representation of in terms of marginal cost curve (so called ‘Cost of Conserved Energy’ – CCE curve), with energy savings expressed in US\$/kWh. Based on CFL sales for 2005 in California and the assumption that the bulbs are used 2.5 hours per day, TCs accounted for almost 70% of the total CCE (Sathaye and Murtishaw, 2004, p. 15). For energy efficient washing machines, TCs account for more than 50% of the total CCE. (Sathaye and Murtishaw, 2004, pp. 23–24). These figures seem too high given the definition of TCs considered in this study, which does not include some barriers and policy failures. In their study focused on large energy intensive firms in the Netherlands, Hein and Block (1995, p. 107) find that information costs vary depending on the type of equipment: 1% for a co-generation installation, 6% for an energy monitoring system. The authors found that for one firm interviewed, estimated information costs vary between 3-4% of all the energy investments. TCs related to decision making account for 1% to 2% of the total investment cost (Hein and Block, 1995, p. 107). Regarding decision-making processes for planning and implementation, Björkqvist and Wene (1993) estimated that on average a family needs 18 hours to decide on an efficient heating system. Using labor rates (1992) as a proxy to estimate TCs, the authors estimate TCs to be in the range of US\$167 and US\$360. This approach does not look

appropriate, however, as a convincing rationale is absent on the use of full cost of salaried time as cost of decision making.

Aggregated estimates. In Joskow and Marron study (1992, p. 10), estimated “administrative costs” (e.g. M&V, promotion of EE) was approximately 30% of the total costs for commercial and industrial energy savings programs. Whereas the estimated scale is still considered to generate cost-effective energy savings, the study conveys some skepticism about the estimates. First, it is argued that these costs are likely to be underestimated because of internal accounting problems. Second, energy savings – critical unit to estimate “administrative costs” as such – are likely to be overestimated due to the fact that they are based on engineering (ex-ante) studies rather than actual (ex-post) measured savings. Regarding the FCEA in Denmark, the estimated scale of TCs is provided in relation to the direct energy audit costs, as opposed to investment costs resulting from the energy efficiency measures. Mundaca and Neij (2006a, p. 11), based on information reported by electricity grid companies, estimated TCs are the range of 5% and 20% of audit costs. In turn, the costs of energy audits under the FCEA – including TCs – would range from 12.6 to 14.4 €cts/kWh respectively. When it comes to the British TWC scheme, TCs were estimated based on a cost-effectiveness analysis with data input provided by subject participants. Estimates of TCs are around 10% for lighting (CFL in particular) and 30% for cavity wall insulation of the total investment costs (Mundaca, 2007b, p. 4348). Easton Consultants (1999; in Mundaca and Neij 2006b) provide an estimation of TCs in relation to EE projects carried out by US Energy Service Companies (ESCOs). Based on a set of interviews, aggregate TCs were estimated to be between 20% and 40% of the total investment (Easton Consultants, 1999, p. 11). Results are summarized in Table 2.

Table 2: Aggregated scale of transaction costs related to energy efficiency technology

Case study	Identified nature of TCs	Scale of TCs	Reference
Life cycle cost of electrical efficiency improvements from utilities perspective	Administrative costs defined as promotion, delivery, monitoring and evaluation of conservation issues.	30% of the costs of the commercial and industrial energy saving program. Higher in the case of residential programmes.	Joskow and Marron (1992, p. 10)
FCEA in Denmark	Costs related to contacts and contracts negotiation during the saving plan phase in the case of the FCEA and the implementation phase in the case of the TWC scheme.	15 to 20% of the direct FCEA activity costs.	Mundaca and Neij (2006a, p. 11)
EEC (phase 1) in Great Britain	Costs occurring during the planning phase of the Energy Efficiency Commitment (EEC1) under the British TWC scheme including information and measurement costs.	10% (lighting) and 30% (insulation) of the total investment costs.	Mundaca (2007b, p. 4348)
ESCOs in the US	Prospecting, proposal, project identification, measurement and verification, funding premium and closing fee.	20 to 40% of the total activity costs.	Easton Consultants (1999, p. 11)

4. Transaction costs related to renewable energy technologies

This section presents the results of our review in relation to the nature and scale (either disaggregated or aggregated) of TCs related to the planning, implementation, and measurement and verification (M&V) phases of RE technologies outside carbon markets. In any event, we acknowledge that it is sometimes difficult to separate or draw a clear line within the project cycle.

4.1. Nature of transaction costs for renewable energy technologies

Transaction cost related to planning. In Skytte et al. (2003) information costs are mostly connected to the planning phase of projects implementing RE technologies. In that study, TCs include the search and pre-feasibility costs relating to the choice of technology to use, the search for partners, and the establishment of a preliminary budget. In a study comparing TCs in the German Renewable Act (Erneuerbare Energien Gesetz, hereafter EEG) that came into effect in 2000¹⁶ and the Renewable Portfolio Standard (RPS) in Texas (US) introduced in 1999 in the context of the restructuring of the state electricity's market¹⁷, Langniss (2003) identifies the search for information as a critical source of TCs, particularly in Texas where calls for proposals are part of the design of the policy, as opposed to Germany which uses the Feed-in-Tariffs as policy instrument to promote the diffusion and commercialization of RE technologies.¹⁸ However, note that in both cases, information may not be lacking as the call for proposals and FiT both are likely to be in the public domain. Firms engaged in RET business can easily obtain this type of information. On the contrary, for new firms, which want to start RET business, this could be the costs related to the entry in the market and a transactions cost.

Transaction cost related to implementation. For this particular phase, the nature of TCs is heavily associated with the negotiation process in order to come to an agreement that leads to the development of concrete projects (Skytte et al., 2003). Likewise, Finon and Perez (2007) argue that contract and negotiation arrangement costs between RE_e producers and obligated parties are intrinsic sources of TCs for certain policy instruments, in particular for TGC schemes or RE quota obligation. The authors found four critical aspects that explain potential sources of TCs with long-term contracts: high volatility and price risk of green certificates within small certificate market, risks on green certificates being added to the wholesale electricity price, intermittence of RE_e generation, and regulatory risks arising from the reformulation of the regulatory framework. A similar source of TCs is found in Nagaoka (2002), who identifies contract negotiation costs given the institutional and political context of the electricity reform. Contracts need to be negotiated and renegotiated by Brazilian electricity suppliers when: (i) the contractual

¹⁶ The German EEG was implemented in 2000. It aims at supporting the development of RE technologies (hydropower, biomass, biogas, wind power and solar energy). It is regulated by Feed-in-Tariffs. Electricity suppliers operating the grid have to pay premium tariffs for renewable generated electricity.

¹⁷ The RPS in Texas was introduced under the governance of George W. Bush in 1999. The targets were the installation of 2,000 MW of renewable energy by 2009 (Langniss and Wiser, 2003).

¹⁸ A Feed-in-Tariff scheme is a policy instrument that aims to foster the deployment of renewable by providing an output-based guaranteed financial incentive over the long run (i.e. minimum guaranteed tariff per kW over a certain guarantee period of time). This payment mechanism, often based on the cost of generation of each different RE technology covered by the scheme, is coupled with the assurance to RE producers of access to the grid.

amount of bagasse has not been delivered, (ii) the regulation changes or (iii) technical failures arise. Negotiation costs are also present in the Texas RPS and are to be borne by both the electricity supplier and the RE Generator (Langniss, 2003). Here, contracts have to be set up and an agreement reached upon. The bidding and the negotiation can be resource-consuming and the preparation for the bidding of contracts alone can incur considerable costs. TCs related to approval procedures are also identified in the literature. These TCs often include time and management devoted to get approval from the authorities for the RE projects so their implementation fulfills the regulatory framework in place (Skytte et al., 2003). The intermittence of RE_e production also creates complexity and uncertainty that can negatively influence long-term contract negotiation (Finon and Perez, 2007).

Transaction cost related to M&V. In the case of the RPS in Texas, monitoring costs are borne by the regulator and consist of monitoring the certification process (Langniss, 2003). In comparison with the German EEG, there are no such costs in the German system due to the difference in design of the policy instruments used (FiTs vs RPS). Approval procedures are also identified in the literature as sources of TCs. They include approval from the regulators for the projects to be in line with the energy policy in place (Skytte et al., 2003). This is also applicable to Tradable Green Certificate (TGC) schemes that have been put in place in several countries, including the Netherlands and Sweden.¹⁹ Under the Swedish and Dutch schemes, TCs are characterized as the costs undertaken by obligated parties beyond costs of meeting the obligation itself (Oikonomou and Mundaca, 2008). For the specific case of the Swedish scheme, TCs represent the costs for electricity producers and suppliers in handling the RE quota obligation on behalf of end-users (Kåberger et al., 2004; Bergek and Jacobsson, 2010).²⁰ This is consistent with Finon and Perez (2007), who also analyze the control of the cost for consumers from a TC perspective. Langniss (2003) explicitly considers the existence of “governance costs”, also referred as political TCs in the literature (see e.g. Furubotn and Richter, 1997). Here, certification costs as such (like in the RPS in Texas), arise from the governmental activity devoted to issue the certificates, audit the generator, and maintain a registry in which certificates are entered (Langniss, 2003). TCs in relation to legal and technical conformity are also identified by Finon and Perez (2007). Enforcement and compliance costs have been identified by Skytte et al. (2003) as a source of TCs. There are costs occurring during the production phase to cover time expenses to ensure compliance is in place and for dealing with potential non-compliant agents. Such costs are also present in the RPS in Texas. In addition, adjustment costs corresponding to the time spent in order to re-adjust the project as of when and how necessary are also mentioned as an important source of TCs. In the Brazilian study, failure to comply with contractual terms

¹⁹ In Sweden, the TGC scheme was introduced in 2002 and was more favourably accepted than other economic instruments (Oikonomou and Mundaca, 2008). In the Netherlands the scheme was introduced in three phases starting in 1998 on a voluntary basis for distribution companies.

²⁰ Note that the initial design of the Swedish TGC scheme allowed electricity suppliers to charge their customers for handling the certificates service that they provided. However, it was found some rent-seeking behaviour on behalf of electricity suppliers because a significant amount of money paid by electricity end users did not reach electricity producers. For further details see Kåberger et al. (2004) and Bergek and Jacobsson, (2010)

between agents on the electricity market gives raise to costs and concerns about the possibility to meet them (Nagaoka, 2002).

Transaction cost related to trading. In the case of TGC schemes, TCs automatically arise as soon as a subject party participates in certificate-based system. Parties may contract a broker to conduct transactions or in some cases proceed with the trading internally (Skytte et al., 2003; Nielsen and Jeppesen, 2003). TCs are also likely to arise if TGC schemes are not fully harmonized which in turn creates trade restrictions (Nielsen and Jeppesen, 2003). Another source of TCs related to trading activity lies in the resources devoted by parties and authorities to register any trade that takes place in the TGC market (Nielsen and Jeppesen, 2003). Interestingly, the reviewed literature does not provide further empirical details. It is argued that parties may not have experiences or resources for trading directly (Skytte et al., 2003). Furthermore, trading behavior may be squelched due to high market volatility and prices risks because of the low market liquidity (Finon and Perez, 2007).

4.2. Estimate scale of transaction costs for renewable energy technologies

Note that most of the reviewed figures presented below address TCs borne by RE producers and/or suppliers and not those TCs borne by consumers. To some extent, TCs borne by the authorities are also possible to identify.

Disaggregated estimates. Skytte et al. (2003) provides disaggregated figures. For the planning phase, TCs represent 9% of the total investment costs (Skytte et al., 2003, p. 66). In the production phase TCs account for 7% of the total investment costs, of which enforcement costs are the highest followed by monitoring and adjustment costs (Skytte et al., 2003, p. 67). As a whole, Skytte et al. (2003, p. 66) arrive at an estimate of TCs equivalent to about 13.5% of total investment costs.

Aggregated estimates. In a comparison of direct transaction costs between the German EEG and the RPS in Texas, Langniss (2003, pp. 230–231) finds that in aggregated terms direct TCs amount for 1.3% of the value of the RE electricity in Germany, and for 2.9% in the RPS in Texas (corresponding to US\$1.7 million per year). Langniss (2003) notes that these costs are relatively low and do not play a determinant role in decisions on different types of RE regulation. In disaggregated terms, the search for potential partners in the RPS in Texas is comprised between 0.04% and 0.3% of the traded value (Langniss, 2003, p. 230). Negotiation and contracting costs range between 0.03% and 0.05% of the traded value for both the RE generator and the retail supplier. In the case of the German EEG, as a comparison, the costs shared by the Federal Ministry of Economics with the Federal Ministry of Environment, Nature Protection and Nuclear Safety for producing a report and organizing round tables amounts to €220,000 annually (Langniss, 2003). With regards to the TGC schemes implemented in The Netherlands, according to a cost calculation conducted by Energieonderzoek Centrum Nederland (Battjes et al., 2000; in Oikonomou & Mundaca, 2008), TCs are assimilated into the regular transaction costs of a bank, around 2.5% of the total activity costs. Indicatively, for 2010, TCs amounted to 0.11 €cts/kWh while 22.7

€cts/kWh for 2020²¹ (Oikonomou and Mundaca, 2008, pp. 224–225). In Sweden, TCs impacted the early performance of the Swedish TGC scheme. In this particular regard, and according to Kåberger et al. (2004, p. 687), 18% of the total costs were accounted as TCs borne by Swedish electricity end-users. However, this specific figure includes profits made by electricity suppliers when transferring the costs of managing the quota to end users. Results are summarized in Table 3.

5. Transaction costs of low-carbon technologies under carbon markets

This section presents the results of our review in relation to TCs associated with low-carbon technologies encouraged under carbon markets. Based on the existing literature, we focus on the Clean Development Mechanism (CDM) Joint Implementation (JI), and the European Union Emission Trading Scheme (EU ETS).²²

5.1. Nature of transaction costs under CDM and JI

CDM and JI are project-activity²³ based mechanisms established under the Kyoto Protocol. ²⁴ It is argued that the cost-effectiveness of JI and CDM is affected by TCs which are often underestimated or ignored (see e.g. Fichtner et al., 2003). Dudek and Wiener (1996) were among the first authors to analyse the concept of TCs in the JI mechanism. They defined TCs as being costs related to search costs, negotiation costs, approval costs, monitoring costs, enforcement costs and insurance costs. We immediately acknowledge that this and successive treatments of TCs are subject to debate. For instance, one can argue that baseline setting or M&V may not be labeled as TCs because they are critical steps for the production of “certified emission reduction”. This aspect is heavily related to the definition of TCs being used by the studies reviewed in this section. A broader discussion of the nature of TCs in the reviewed studies, and their determinants, is presented in Section 6.

²¹ These figures are calculated in this study based on the GC scenario (ECN) where energy demand is 3.7 EJ in 2010 and 4.2 EJ in 2020. RE targets are hence 0.2 EJ in 2010 (474 PJ) and 0.4 EJ (640 PJ).

²² Note that for the case of tradable permit schemes in general (not for GHG emissions in particular), there is extensive literature about the negative effects of TCs. Several authors have argued that TCs play a key potentially negative role in emission trading systems (Hahn and Hester, 1989; Heller, 1998). According to Stavins (1995), TCs can make trading schemes less cost-effective. Montero (1998) argues that transaction costs and uncertainties reduce the level of efficiency, making the post-trading outcome different from the least-cost equilibrium. Tietenberg (2006) elaborates on how TCs can reduce the attractiveness to trade and the actual amount of permits being traded.

²³ According to Conference of the Parties (COP) “a project activity is a measure, operation or an action that aims at reducing greenhouse gases (GHG) emissions”. The Kyoto Protocol and the CDM modalities and procedures use the term “project activity” as opposed to “project”. A project activity could therefore be a component /aspect of a project undertaken/planned”. For further information see Executive Board. Seventh Meeting –Annex 4: Glossary of terms used in the CDM project design document (CDM-PDD). Available: <http://unfccc.int/cdm> [February 20, 2003]

²⁴ Together with an International ETS, note that the EU “bubble” has also been labelled as another flexible mechanism. The “EU Bubble” refers to the group of European countries that share a joint target. This one is the sum of the original country targets, which is then reallocated among its participants. Overall, this group of countries has to reduce emissions by 8% by 2012 compared to 1990 levels.

Table 3: Aggregated scale of transaction costs related to renewable energy technology

Case study	Nature of Transaction Costs	Scale of Transaction Costs	Reference
Admire Rebus Report	Search and pre-feasibility, negotiation and development, approval and administrative procedures (planning phase)	9% of total investment costs	Skytte et al. (2003, pp. 66-67)
	Monitoring (accounting and verification), enforcement and adjustment costs (production phase)	7% of total investment costs	
Trading of Green Certificates, the Netherlands and Sweden	Costs undertaken by obligated parties beyond costs of meeting the obligation itself; including costs to handle quota obligation on behalf of end-users (for the specific TGC scheme in Sweden)	2.5% of total activity costs 18% of the total costs	Oikonomou and Mundaca (2008, pp. 224–225); Kåberger et al. (2004, p. 687)
Renewable Portfolio Standard, Texas (US)	Search, negotiation and contracting, metering/auditing/billing, paying/monitoring, calculation of obligated amounts, submission of certificates, monitoring, enforcing, issuance of certificates, reporting and adapting, application for certificates.	2.9 % of the value of the RE electricity	Langniss (2003, p. 230)
German Renewable Act	Direct TCs (excluding indirect TCs being costs 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	Langniss (2003, p. 231)
Sugar cane for electricity generation, Brazil	Search and information, risks related to non compliance (fines), negotiation and renegotiation of contracts, insurance, compliance.	n/a	Nagaoka (2002)

That said, the German Federal Ministry of the Environment, Nature, Conservation and Nuclear Safety (2007) also identified several sources of TCs. According to this organization, TCs include costs for the Programme Design and Document (PDD) development and baseline determination, approval from the relevant designated national authority (DNA), validation, and registration at the CDM Executive Board. Based on the application of the Delphi method, it is found that one of the most important sources of TCs is the PDD. The PDD includes the calculation of the baseline emissions of the project which represent a burdensome task, as well as the demonstration of additionality required for the validation of the project. The project developer must be able to prove that emissions reductions are “additional” in comparison to what would have occurred under business as usual.

For the specific case of small-scale CDM wind-energy projects, Mundaca and Rodhe (2005) identified the nature of TCs and provide quantitative estimates, albeit aggregate. Identified TCs include negotiation with potential developers and CERs buyers, ensuring host country approval, setting the emission baseline and additionality, validation of the baseline, development of monitoring plans, contracting international auditing, etc. TCs were estimated on the basis of two sources: information obtained from wind energy developers in India, and data obtained from consultancies already providing

these services at that time.

In his review of the CDM market, Sovacool (2010) considers that the design of this mechanism incurs substantial TCs due to the design of the project, the review and audit, the evaluation.

5.2. Estimated scale of transaction costs under CDM and JI

Krey (2005) conducted a study to quantify TCs in 65 unilateral Indian CDM projects. Using surveys, the study estimates that total TCs range between US\$0.07/tCO₂ to US\$0.47/tCO₂ (Krey, 2005, p. 2385). In some projects TCs account for 2.2% to 13% of the CER price paid (Krey, 2004, p. 91). The costs associated with the PDD along with the costs related to find a buyer, to validate the project and the cost adaptation fee, represent the main share of TCs for projects with emission reduction lower than 1MtCO₂ over the crediting period. Boyle et al. (2009) also finds that the development of PDD is an important cost driver along the level of complexity of the baseline determination and demonstration of additionality in CDM projects.

The already mentioned study published by the German Federal Ministry of the Environment et al. (2007) notes that for large scale CDM and JI projects, TCs for project development amount to between US\$50,000 and US\$100,000 (German Federal Ministry of the Environment et al., 2007, p. 82). For smaller projects, TCs are below US\$50,000 (German Federal Ministry of the Environment et al., 2007, p. 82). MRV costs represent the major sources of TCs, and the more complex the baseline is (and resulting the required monitoring) the higher the TCs are. Interestingly, the study notes that in the first round of JI, TCs were much higher than later on in the process, suggesting the 'learning effect' also mentioned by Michaelowa and Jotzo (2005).

In the case of small-scale CDM wind-energy projects studied by Mundaca and Rodhe (2005, p. 406), based on the information obtained from wind energy developers in India and data obtained from consultancies already providing these services, ex-ante implementation TCs are estimated to be US\$150,000 per wind farm regardless its size (Mundaca and Rodhe, 2005, p. 406). This includes costs such as negotiation, approval, baseline, and validation. When it comes to the ex-post TCs, these are estimated to be US\$25,000 per crediting period, covering costs such as monitoring, verification and certification (Mundaca and Rodhe, 2005, p. 406). Depending on the size and performance of the projects, the estimates of TCs per CER vary considerably: between US\$2 (for a project with an installed capacity of 4.8 MW and capacity factor of 17%) and US\$34 (for a project with an installed capacity of 0.25 MW and capacity factor of 20%) (Mundaca and Rodhe, 2005, p. 413).

Michaelowa and Jotzo (2005, p. 514) give estimates of TCs for CDM projects funded by the Prototype Carbon Fund (operated by the World Bank). Typically, pre-implementation TCs in the life cycle of a CDM project amount to €390,000. However, given uncertainties (e.g. in relation to the entry into force of the Kyoto Protocol) and lack of experience (e.g. consultancies offering CDM pre-implementation services) at the time the study was conducted, the authors estimated that pre-implementation TCs could range from €242,000 to €713,000 per project. In addition, the analysis done by Michaelowa and Jotzo

(2005, p. 515) shows geographical differences: TCs including pre-implementation, implementation and certification, in the electricity sector in North Africa are estimated to be €0.52/tCO₂, against €0.29/tCO₂ in South America for an almost identical reduction of CO₂ emissions.

Michaelowa & Jotzo (2005) also focused their study on the pilot phase of JI, launched back in 1995 (called, Activities Implemented Jointly [AIJ]).²⁵ TCs related to technical assistance and administrative costs in AIJ represented 20.5% of total project costs in EE projects, and 14.4% in RE projects (Michaelowa and Jotzo, 2005, p. 513). Those ranges vary considerably from one analysis to another leading to look at the impact on the TCs of the type and size of projects. Based on Swedish AIJ projects developed in the Baltic States, estimates for EE project range from 2.7 to 123.9 €/tCO₂ and estimates RE projects are between 1.3 and 11.1 €/tCO₂ (Michaelowa and Jotzo, 2005, p. 514).

Following on the case of the AIJ, Fichtner et al. (2003, p. 252) find that the share of TCs represent between 6% and 53% of the total costs of the projects. Technical assistance represents half of the TCs. Administrative costs accounts for 36%, follow up costs 12% and reporting costs only 2%. With regards to the total project transaction costs, Fichtner et al. (2003) found that the mean share value of the total project TCs to implement EE projects represent 13% of the total cost, while in RE projects it represents 20%.

Results are summarized in Table 4.

Table 4: Estimated scale of TCs under Kyoto Flexible Mechanisms

Mechanism	TCs categories	Project type	TCs estimates	Reference
AIJ	Technical assistance, follow up, administration, and reporting	32 EE, 27 RE, 3 Forestry, 1 Agriculture and 1 reforestation	US\$0.05-\$261/tCO ₂	Fichtner et al. (2003, p. 252)
AIJ (Sweden)	Technical assistance, follow-up, administration, and reporting	26 EE and 21 RE	For EE: €2.7-123.9/tCO ₂ For RE: €1.3-11.1/tCO ₂	Michaelowa and Jotzo, (2005, p. 514)
CDM (under the PCF)	Negotiation, approval, monitoring, verification, and validation	Agriculture, electricity	US\$0.2- \$0.74/tCO ₂	Michaelowa et al. (2003, p. 268)
CDM (India)	Search, negotiation, PDD, approval, validation, registration, monitoring, verification & certification, and adaptation fee	EE & RE, Waste	US\$0.07-0.47/tCO ₂	Krey (2005, p. 2393)
CDM (India)	Negotiation, approval, baseline setting and additionality, validation of the baseline, monitoring, and contracting international auditing	Small-scale wind energy	US\$2 - US\$34 in TCs per CER	Mundaca and Rodhe (2005, p. 413)

²⁵ Prior to ratification, some countries including Sweden, launched a pilot phase commonly referred to as "Activities Implemented Jointly (AIJ)" in order to test the provisions of the Protocol.

5.3. Nature of transaction costs under the EU-ETS

Jaraite et al. (2009) identified TCs using Ireland as case study during the pilot phase of the EU-ETS (2005-2007). The study identified three categories of TCs. *(i)* Early implementation costs (prior to 2005). These costs are fixed and include internal costs (e.g. management, staff training), consultancy costs and capital costs related to monitoring, recording and data and storage equipment. These costs are one-time costs and include the measurement of baseline emissions, as well as the functioning of the market as the two most important sources of TCs. *(ii)* Monitoring, reporting and verification costs. These costs are periodic and include the preparation of an annual report which must be verified, along with the emissions reported. They represent a combination of internal costs and consultancy costs. *(iii)* Trading costs. These costs are variable and are incurred only by firms that are trading their allowances. They depend on the number of transactions performed, the volume of the trade and the fees involved which can vary from one broker to another.

When analyzing the auctioning of allowances under the second phase of the EU ETS, Hepburn et al. (2006) address TCs in relation to negotiation over permits. Within this context, it is argued that political and policy decisions on how to apportion allowances across subject participants generate an intensive lobby activity by them that aims to maximize potential benefits. Thus, all the resources devoted by subject parties; including policy makers, politicians, consultancy and researchers, to this relevant and critical rent allocation process represents an immense source of TCs (Hepburn et al., 2006).

Schleich and Betz (2004) examine TCs for small and medium sized (SMEs) companies under the EU ETS. In their study, two main sources of TCs are identified. The first group of TCs refers to those that emerged directly from the implementation of the Directive 2003/83/EC²⁶ establishing the EU ETS as such, namely the costs related to the application procedures for allocation and permits, costs associated with service charges for the accounts in the registry or costs for monitoring, and verification and reporting CO₂ emissions; including costs related to national tax and balance-sheet issues of allowance trading. The second group refers to those TCs that arise from the process of maximizing the possible share of rents from the trading scheme as such. In this case, for instance, sources of TCs are related to the need of mapping out and assessing (potential) mitigation measures, carrying out dedicated studies (e.g. sensitivity analyses), searching for trading partners, and performing carbon transactions. Schleich and Betz (2004) argue that some of the TCs only accrue once at the beginning of the EU ETS. For example, costs for application procedures for allocation and permits. Others accrue annually, such as M&V costs, and yet others depend on the number of trades or the trading volume, such as costs for finding trading partners.

5.4. Estimated scale of transaction costs under the EU-ETS

The magnitude of the initially addressed 72 companies, of which 27 have replied as well as the applied methodology (survey followed by face-to-face interviews) provide a good representation of the scale and

²⁶ For details see <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:EN:PDF>

burden of TCs in the EU ETS. One of the main findings of the study done by Jaraite et al. (2009) lies in the fact that the most significant TCs arise in the early phase of the implementation. Within this early implementation phase, TCs incurred by organizations in relation to baseline setting and the functioning of the EU ETS market represent the two most significant sources. In absolute terms, the initial costs tend to be higher for large organizations compared to medium and small organizations. However when TCs are apportioned in terms of CO₂ emissions, the finding is the opposite: early implementation costs for large organizations represent 3€cts/tCO₂ and 51€cts/tCO₂ for small ones (Jaraite et al., 2010, p. 196). This finding highlights the importance of project size and (potentially) unequal distribution of administrative costs borne by participants of different sizes. The same study provides estimates for MRV costs: 2€cts/tCO₂ for large companies and €1.51/tCO₂ for small size firms (Jaraite et al., 2010, p. 198). Due to the (large) nature of projects, large and medium companies tend to spend more on monitoring compared to small organizations. In small organizations, half of the MRV costs are devoted to verification. On average, implementation and MRV costs represent 8€cts/tCO₂, less than 1% of the allowance price, which was €11.60 as of 23 January 2009 when the study was conducted (Jaraite et al., 2010, p. 201).

Trading costs tend to be variable as opposed to MRV and implementation costs since they are proportional to the amount traded. Amongst the 27 responding organizations, 11 Irish companies proceeded with trading: 6 sold allowances and 5 bought allowances. All the companies traded through an external broker. The study does not provide a quantification of those costs, but cites a brokerage fee per ton of traded allowance from 10€cts in January 2005 to 6€cts in August 2006 (Jaraite et al., 2010, p. 200).

6. Factors influencing transaction costs

The findings from our review strongly underscore that it is problematic to draw general conclusions about the nature and scale of TCs. All TCs seem to be case- and context- specific. The question then is what makes all the cases so unique. To address this aspect, we re-visited all the cases in order to better understand the drivers and specific contexts that determine the nature and scale of TCs. As shown in Table 5, determinants of TCs can be classified in three categories: (1) endogenous factors that are inherent to the projects (e.g. characteristics of the technologies), (2) exogenous factors which relate to different contexts including the institutional and legal frameworks in which TC are occurring, and (3) intrinsic factors such as the conceptual choices and the methodologies used by the researchers. These aspects are briefly elaborated and discussed in the following sections.

Table 5: Identified factors influencing the nature and scale of analysed TCs studies

Endogenous factors	Exogenous factors	Intrinsic factors to the approach used
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<ul style="list-style-type: none"> • Type, size, objective and performance of low-carbon technologies • Level of reliability and accuracy of: <ul style="list-style-type: none"> ✓ Data sources ✓ Technical parameters ✓ Baselines and M&V methodologies • Level of awareness and accountability of TCs 	<ul style="list-style-type: none"> • Nature of the parties • Legal framework of policy instruments • Specific (energy) market conditions • Geographical context 	<ul style="list-style-type: none"> • Conceptual choices regarding TCs • Methods, assumptions and approaches used for quantitative estimations • Scope and boundary of analysis • Functional unit used to quantify TCs
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6.1. Endogenous factors

When it comes to the type, size, objective and performance of low-carbon technologies in relation to emission reductions, one can observe that the size of carbon mitigation projects is an important factor determining the *scale* of TCs. However, and because some of the identified sources of TCs entail fixed costs (e.g. baseline development) the actual *burden* can decrease with increased volume of carbon reductions. Whereas the scale of TCs can have a fixed or constant component regardless of the size of the project, the burden can decrease with an increased volume of emission reduction. For instance Michaelowa and Jotzo (2005) reported that EE projects implemented under AIJ of a size below 100t/CO₂ per year have considerably higher transaction costs than projects that reduce between 500-1,000 tCO₂ per year. For the particular case of EE, other reviewed studies conclude that it is the size and performance of technologies, measured for instance in terms of carbon emission reductions or saved energy, that ultimately determines the size of TCs (e.g. Björkqvist and Wene 1993; Michaelowa et al. 2003; Ostertag, 1999).

The level of reliability and accuracy of several technical aspects is identified in most (if not all) of the reviewed studies. One can attribute this difference to the fact that the level of uncertainty and number of intermediaries in EE investments is likely to be much higher than in the case of RE. It can be complex to measure the actual energy savings performed from one technology to another. For instance, investments in wind power installations are argued to have a relatively low risk and most TCs tend to have a fixed component (Mundaca and Rodhe, 2005). Thus, one can infer that wind power projects with large capacity will incur relatively lower M&V costs compared to the implementation of a specific EE device for a particular industrial process. Household technology choice on the contrary, is often affected by a number of intermediaries (e.g., project developers, construction companies, equipment dealers), increasing the number and complexity of transactions (cf. Lutzenhiser, 1993). Following on the level of reliability and accuracy of technical aspects, baseline setting and resulting M&V activities are also relevant. For instance TCs play an important role due to the fact that the financial sustainability of CDM or JI is very much dependent on the size of the CER revenue stream (Chadwick, 2006). The same can be said for energy savings credits generated under Tradable White Certificate (TWC) schemes (Mundaca, 2007b). Like

TWC schemes, JI and CDM mechanisms are project- and credit-based mechanisms where emission reductions are accounted against a baseline which describes what would have occurred if the JI or CDM project would not have been implemented. This stresses the hypothetical nature but critical role of any baseline setting, which is very likely to be much more costly for the case of EE than for RE technologies. (cf. Michaelowa and Jotzo, 2005). Yet, it will more likely be EE versus RE technologies that can yield benefit and be adopted even without policy, so this baseline argument cannot be generalized. Again, the complexity of the mitigation project is likely to determine the complexity of the baseline setting and thus corresponding costs.

It is possible to recognize what we would call a ‘Transaction Cost Accounting Problem’. As Joskow and Marrow (1992) put it, this refers to the fact that project developers, although sometimes fully aware of the existence of TCs, do not keep track of these costs and estimations are proxies often resulting in underestimated values. According to Joskow and Marron this can be by a factor of two or more on average. Mundaca and Neij (2006a) also note the different level of accounting (and awareness) when analyzing the FCEA in Denmark: 35% of respondents could not evaluate TCs in relation to the direct energy audit costs. Joskow and Marron (1992) find significant variations and therefore look for systematic bias in their own estimations. Although not explicitly addressed in the reviewed studies, uncertainties and differences could also be explained by the fact that project developers or key stakeholders are reluctant to disclose some type of information for commercial or strategic reasons. With a limited access to relevant information, extra challenges are imposed for understanding the magnitude of TCs.

6.2. Exogenous factors

Our review reveals the importance of the nature of the parties and how they are affected by TCs. For instance Morrison et al. (2008), Ducos et al. (2009), and Mettepenningen and van Huylenbroeck (2009) recommend taking into consideration the trust between the parties in TCs analysis. Trusting relationships do contribute to reduce TCs as it facilitates the contract negotiation and reduce the search and associated administrative costs (Mettepenningen and van Huylenbroeck, 2009).

Following on the role of parties, Langniss (2003) not only identifies and estimates TCs, but also allocates costs between the different parties involved in the German EEG and the implementation of the RPS scheme in Texas. In this context, establishing a comparison between the two implemented policies can provide useful insights in analyzing which parties bears more or less TCs: the energy generator company, the grid operator, the retail supplier, and/or the regulator. For instance, it becomes clear that in the context of the FiT's policy implemented in Germany, the costs attributed to the regulator are minimal, namely producing an annual report and organizing round tables. On the contrary, in a different type of policy context, the RPS in Texas, such costs are higher since the regulator is required to allocate resources in monitoring, enforcing, issuing certificates and reporting (Langniss, 2003).

If we now turn our attention to the legal frameworks of policy instruments, our review highlights

that the design of policy instruments can play a significant role to reduce TCs. For instance, in the case of the German EEG, there are no TCs related to searching for information and negotiation of contracts since the identity of the buyer, the level of remuneration and the deliverable amount of electricity are determined by the law (Langniss, 2003). For the case of EE, the regulatory framework of the British TWC scheme allows the certification of energy savings based on ex-ante M&V approach. This approach involves simplified procedures with savings and thus baselines are agreed in advance. Energy savings are calculated based on standardized estimates between the reference scenario (or baseline) and the performance of the eligible measure. This is supported by the fact that the technical performance of eligible measures (e.g. CFL) can sometimes be well understood so the level of uncertainty is very low.

Different institutional frameworks can also explain different findings in the nature and scale of TCs. For example, Michaelowa et al. (2003) argue that negotiation and verification costs fall over time. The absence of ex-post M&V costs under the British TWC scheme is contrasted with the presence of TCs related to this specific source under the Italian TWC scheme (Mundaca, 2007b). In the case of the CDM, the difference in institutional frameworks in countries or states or organizations that want to enter in a bilateral agreement can generate significant TCs in negotiating for example. TCs might be more significant in countries with inefficient institutional frameworks (Michaelowa and Jotzo, 2005). Strong institutional barriers can also be found in countries where bribing may constitute a standard practice (De Soto, 1989). 'Red tape' regulation or excessive bureaucratic measures may also affect TCs. Hahn and Hester (1989) argues that administrative requirements for some types of emissions trading affect TCs. All the studies, either implicit or explicit, highlight specific market conditions influencing the nature and scale of TCs. For instance, Skytte et al. (2003, p. 40) argue that, according to several studies (Klaassen and Nentjes, 1997; Montero, 1998; MMA, 1999), brokerage fees are estimated to 5% of the total traded value within national trading and may vary between 2% and 10% in the case of international trading. Such fees depend on the type of market on which the trade is taking place and the degree of maturity of the markets. Thus, due to reasons of inexperience or lack of resources (staff), organizations may tend to use a brokerage firms. Consistent with this situation is the experience under the British TWC scheme. Mundaca (2007b, p. 4346) found that brokers (or 'managing agents') facilitated arrangements between suppliers and local authorities. Where niche markets existed, they bundled disaggregated customers. Brokerage fees amounted up to £10 per installed insulation measure or customer identified. Mundaca (2007b) concludes that whereas the participation of intermediaries (i.e. local authorities, landlords, charity organizations, and managing agents) added to TCs under the British scheme, it also helps to reduce them: interviewees agreed that without these actors TCs would have been probably higher.

6.3. Intrinsic factors

All the reviewed studies made their own conceptual choices. Classifications of TCs do support the systematization of the treatment of data collected and can also facilitate (with due caution) comparisons between cases (McCann et al. 2005), as in the case of the Kyoto Protocol mechanisms. Largely driven by the regulatory frameworks, the research approaches used, for instance, by Michaelowa and Jotzo (2005),

Fichtner et al. (2003), Krey (2004) and Mundaca and Rodhe (2005) in classifying TCs under the Kyoto Flexible Mechanisms contain conceptual similarities regarding the different sources of TCs (e.g. negotiation, approval, M&V activities).

In turn, conceptual choices have an impact on the scope or boundary of the investigation and thus nature, scale and resulting burden of TCs. If we strictly follow Coase's definition, one can argue that elements of TCs included under carbon markets may not qualify for TCs. This is because the CDM or JI processes that must be followed by project activities –such as registration, verification, certification- are necessary “production” steps for certified emission reductions. The same argument could be given for similar production steps involved, or required, in tradable certificate schemes for renewable energy and efficiency improvements. In all these markets, what is traded here is ‘certified emission reduction’, ‘certified energy savings’ or ‘certified renewable energy production’, and not emission reductions *per se*. Another aspect to consider is the frequency and the time dimensions of TCs. Costs can be broken down as one-time costs, ongoing or fixed costs (MRC, 2004), and proportional (Michaelowa et al., 2003). For instance McCann et al. (2005) argue for a chronological classification for the measurement of TCs. While information costs may occur throughout the whole life of a project, contracting costs are likely to occur only during the implementation of the project. Such aspects must be carefully considered when determining conceptual choices as they influence interpretations and may or may not facilitate relative comparisons throughout the research field.

The quantification of TCs is a very complex exercise. It is thus no wonder why all the reviewed studies focus heavily on specific endogenous factors. Common to all of the reviewed studies is the need to analyze TCs at the micro level, which is consistent with Williamson (2010), who argues the need to examine economic organization at the microanalytic level. Within this context, the scale and resulting burden of TCs are estimated based on a variety of methods including: a ‘Total Resource Cost’ (utility) model (Joskow and Marron, 1992), ‘Energy Conservation Curves’ (Sathaye and Murtishaw, 2004), ‘Carbon Abatement Curves’ (Krey, 2005), and ‘Cost-effectiveness Analysis’ (Mundaca, 2007b). The model used by Joskow and Marron (1999) compared the costs and savings of DSM programs against known projections for the same types of costs and savings. The model focuses on the life-cycle cost of electric efficiency investments before taking into account the associated savings in electricity costs. Sathaye and Murtishaw, 2004 et al. (2004) focused on energy efficiency options and the representation of their marginal cost curves (i.e. cost of conserved energy (CCE) curves). The method quantifies the costs and benefits faced by consumers. The approach adopted by Krey (2005) estimated marginal carbon emission reduction cost and their relation to specific TCs. Mundaca (2007a) focused on the cost of energy savings. Similar to the approach used by Joskow and Marron (1999), the method aimed to quantify aggregated TCs based on the lifecycle stage of energy efficiency projects. However, unlike Joskow and Marrow, net financial benefits for end-users were estimated using actual residential energy prices (electricity and natural gas) as benchmarks. To populate these models, information and parameters come, for example, from statistical data, surveys, interviews and secondary data. In the case of the Kyoto Protocol mechanisms, studies source figures

coming directly from consultants offering related services (e.g. baseline setting) or from actual projects contained in the UNFCCC databases. For surveys, an important criterion is the sample size (in relation to the statistical universe) of responses, which is crucial in establishing the confidence level of the estimates. Some studies explicitly acknowledge this limitation (e.g. Hein and Blok, 1995; Mundaca, 2007b). One of the main reasons for having low statistically representative samples lies in stakeholders being reluctant to disclose information and thus participate in TCs related research. Logically, all methodologies that quantify TCs also entail numerous assumptions and expert input. As a whole, the methodologies applied to quantify of TCs have to be interpreted with reserve and precautions.

TCs are expressed in most cases as a proportion of total investment costs or a portion of carbon credits. TCs are evaluated in different functional units (e.g. as percentage of investment costs; as burden per issued CER or size of emission reductions) making comparisons impossible and emphasizing further that TCs are highly case- and context-specific. Therefore, in order to interpret TCs estimated values, it is essential to confront them to relevant parameters within the context of the projects or the investments. For instance, as in Michaelowa and Jotzo (2005), parameters for the impact of implementation and TCs in CDM projects are presented in three different scenarios (standard, low- and high- CDM TCs) and include the international sale price, the total CER sales, the CDM revenues and the share of CDM in the global carbon market.

Related to the transaction cost accounting problem mentioned previously, the level of awareness of respondents themselves is an important intrinsic uncertainty aspect to consider when analyzing the data collected. As part of the evaluation and the level of awareness about TCs, Skytte et al. (2003) provide an interesting self-assessment on the knowledge of the respondents on lead times and TCs. Based on a qualitative survey filled by 44 respondents, 17% of them consider to have a “expert knowledge” on TCs, around 30% a “moderate knowledge” and 28% have “little knowledge” (the remaining did not answer). There are some gaps in the completion of the survey: 12 respondents provided values for the total planning phase (without distinguishing sub-costs); 12 respondents evaluated the total production phase and their sub-costs; 13 respondents provided a value for the search and pre-feasibility costs as well as negotiation and development; only 8 values were given for the total costs of the project illustrating some lack of knowledge and the complexity in evaluating TCs. In turn, Skytte et al. (2003) note some discrepancies between the cumulative values of all the phases of the project and the single value provided for each phase. For instance the cumulative values provided for the planning phase is twice as high as the disaggregated cost estimation provided for the planning phase. The same has been observed for the production phase. Skytte et al. (2003) attribute this discrepancy to the fact that respondents tend to overestimate the value of each sub-cost.

7. Conclusions

The objective of this report was to provide a comprehensive review of the empirical literature addressing transaction costs of GHG mitigation technologies. The review addresses transactions costs related to both market behavior (e.g. information asymmetries, trading activity) and policy conditions (e.g. regulatory

frameworks) that can prevent the realization of *seemingly* cost-effective GHG emission reduction potentials.

The first hurdle to overcome when analyzing transaction costs is theoretical rather than empirical. We find numerous conceptual discrepancies that, to a greater or lesser extent, have an impact on the methodological choices that framed the reviewed studies. We have also attempted to provide some clarifications regarding the typology of transaction costs affecting low-carbon technologies. Our review also documents the potential size of transaction costs in energy and policy-driven carbon markets (e.g. CDM), that can negatively affect (i) the financial feasibility and environmental benefits of low-carbon technologies, and (ii) the performance of the policy instrument creating markets for the diffusion and commercialization of these technologies.

The review leads us to conclude that transaction costs are highly project- and context- specific and, in this perspective, it is not advised to make generalizations, in particular for policy design and instrument choice. For the case of energy efficiency, the number of sources – or different natures – of transaction costs can be largely explained by the uncertainties, risks and complexities that energy efficiency measures involve. As far as renewable energy technologies are concerned, the identified sources suggest – relatively speaking – fewer sources of transaction costs.

We found that the nature, scale and thus burden of transaction costs related to low-carbon technologies are very likely to differ because of a number of endogenous, exogenous, and intrinsic methodological determinants. Endogenous factors include the type, size, objective and performance of GHG mitigation technologies. Exogenous factors also seem to strongly influence the magnitude of transaction costs. These include the nature of the parties, the legal framework of policy instruments, specific (energy) market conditions, and geographical contexts that can play a critical role affecting the nature and scale. In particular, the choice of design elements can affect several aspects of the operation and implementation of policy instruments, which in turn, can create (or reduce) transaction costs for subject parties.

We also identified intrinsic elements that can lead to estimates of transactions costs differing across studies. These include conceptual choices, quantitative methods, assumptions and functional units used in estimations, and research boundaries. However, it appears that the exogenous and endogenous determinants considerably affect the level of uncertainty and the differences in magnitudes of estimates, even if similar technological dimensions are analyzed with similar methods.

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