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Palm, Jenny; Bryngelsson, Emma

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ORIGINAL ARTICLE

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Jenny Palm · Emma Bryngelson

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Abstract The construction industry is an important societal sector and a major consumer of energy. Improved energy efficiency is important for this sector, but energy efficiency at construction sites has so far been under-researched. The aim of this article is to analyse the drivers of and barriers to improved energy efficiency at construction sites, as perceived by professional actors. The peer-reviewed research and the grey literature on the topic were reviewed, and semi-structured interviews were conducted with 20 relevant professionals in Sweden. The identified barriers were related to lack of money, split incentives, lack of standards and procedures, low electricity prices, lack or regulations, lack of knowledge and information and the conservatism of the industry. The identified drivers were regulations forcing actors to implement energy efficiency, environmental and building certifications, internal education, be part of an industry network, engaged electricity utility company providing information, supportive top and site managers, competition between construction sites, the existence of a plan, checklists or project database, back-office support and client demand of energy efficiency.

Keywords Construction site · Energy efficiency · Barriers · Enablers · Motivation · Drivers

J. Palm (✉) · E. Bryngelson
International Institute for Industrial Environmental Economics (IIIEE), Lund University, Box 196, 221 00 Lund, Sweden
e-mail: Jenny.palm@iiiee.lu.se

Introduction

For the global energy system to implement the Glasgow Climate Pact Paris and keep global warming below 1.5 °C, energy efficiency must be one of several important means by which industry reduces its environmental impact. Earlier research has found that potential energy-efficiency measures are often not implemented, meaning that an energy-efficiency gap exists (Backlund et al., 2012; Hirst & Brown, 1990; Thollander et al., 2019). This gap has been analysed in relation to, for example energy-intensive production (e.g. Worrell et al., 2009), SMEs (e.g. Trianni et al., 2016) and the building sector (e.g. Palm & Reindl, 2018). Fewer studies have examined energy use and energy efficiency at construction sites, which is the focus here.

The construction industry is an important societal sector that satisfies needs for buildings and facilities. However, the sector is also a major consumer of energy, representing 36% of global final energy use and 37% of energy-related CO_2 emissions (United Nations Environment Programme, 2021). These global figures are also reflected in Sweden, the case studied here. Efforts to address climate change and reduce greenhouse gas (GHG) emissions must include this sector. Previous calculations established the

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assumption that only 15% of the energy use in buildings comes from the production phase (i.e. upstream), whereas 85% comes from the operation phase (i.e. downstream). However, buildings have become more energy efficient, causing a shift to 50/50 upstream and downstream energy use in buildings (Liljenström et al., 2015; Westerlund et al., 2014). With few exceptions (see next section), earlier research has paid little attention to construction sites and their potential to reduce energy use and GHG emissions. This article accordingly aims to fill this research gap and analyse the drivers of and barriers to improved energy efficiency that professional actors perceive at construction sites.

The remainder of the article is structured as follows. First, the barriers to and drivers of energy efficiency discussed in earlier research are summarised. Then, the methods and material used here are described. This is followed by a Swedish empirical study of the barriers and drivers experienced by stakeholders at construction sites. Finally, a discussion and conclusions end the article.

Barriers to and drivers of energy efficiency in earlier research

There is a lack of research in the area of energy efficiency at construction sites. Most relevant studies are master's theses and reports, but there are few peer-reviewed articles. Studies of energy efficiency at construction sites are fairly recent, the oldest publication found being a master's thesis from 2005. These studies mostly have a technological focus in which technical equipment is tested or evaluated, but some studies examine renovation projects and processes. These studies will be discussed below, together with earlier studies of energy efficiency in the building sector in general, to see what barriers to and drivers of energy efficiency have been identified in earlier research and how these findings can advance the analysis of energy efficiency at construction sites.

Energy use at construction sites

At a construction site, diesel and electricity are estimated to be the most used energy sources. In a Swedish study from 2020, diesel was estimated supplying 55% and electricity 34% of the energy consumed at a construction site (Nakos Lantz, 2020). Energy-intensive issues on construction sites identified in earlier studies concern lighting, construction containers, equipment containers, construction cranes and other equipment such as smaller machines and construction fans. Other things using electricity on a construction site is clothes drying, electrically warming up concrete and storage of building materials (Alexandris, 2011; Bartenev et al., 2021; Hatami, 2010; Nakos Lantz, 2020).

Several recent studies identified construction containers as a main source of energy usage at construction sites (Korol & Dudina, 2019; Nakos Lantz, 2020). Construction containers are built for temporary usage, for example as offices, dressing rooms or storage, and these containers must remain at a comfortable temperature in accordance with work environment rules. Lack of insulation in windows and doors together with temperature regulation and human behaviour all contribute to high energy usage in construction containers. In regular containers, the doors and windows are too thin to isolate the heat, and the doors often lack automatic closers (Alexandris, 2011). The highest energy usage in containers comes from heating them (Bergqvist & Smedberg, 2017), caused by the lack of insulation and the habit of not closing doors and windows. There are several ways of reducing the energy used by construction containers. Norms and practices of energy efficiency are influenced by material aspects, such as building structure, location and production type as well as the age and condition of the technical equipment and machinery (König, 2020). Solar panels could also be installed on containers to provide electricity to the offices or parts of the construction site (Bergqvist & Smedberg, 2017).

There seems to be potential to improve energy efficiency at construction sites. Next, earlier research on energy efficiency with a specific focus on barriers to and motivations for implementing measures leading to improved energy efficiency will be discussed.

Barriers to and drivers of improved energy efficiency

In earlier research, it is well established that cost-effective energy-efficiency measures are not always implemented. This discrepancy between optimal and actual implementation is referred to as the energy-efficiency gap or the energy paradox (see, e.g.

Blumstein et al., 1980; Backlund et al., 2012). Barriers are factors accounting for the reluctance to adopt cost-effective energy-efficiency measures, and earlier research has commonly systematised them into broader categories, such as economic, organisational, regulatory, institutional and behavioural barriers (e.g. Palm & Reindl, 2018; Sorrell et al., 2000; Thollander et al., 2010). Such barriers can be removed, avoided or reduced (Reddy, 2013). Motivations for or drivers of energy efficiency are factors that encourage and inspire companies to become more energy efficient (Cagno & Trianni, 2013; Solnørdal & Foss, 2018; Trianni et al., 2017). Drivers of energy efficiency have also often been systematised into broader categories, often reflecting the categories used for barriers, such as economic, organisational, behavioural, policy and regulatory, informational, knowledge and communication, and technological drivers (Hampton, 2019; Palm & Backman, 2017; Solnørdal & Foss, 2018).

As mentioned above, energy efficiency at construction sites is under-researched. For this reason, studies of energy efficiency in relation to other subjects have been used here to gain an overview of potentially relevant barriers to and drivers of improved energy efficiency at construction sites. Earlier studies of, for example building renovations, low-energy buildings and low-energy industries have been used when searching for barriers and drivers potentially relevant to construction sites. These studies will be summarised below, along with related categories, starting with potential barriers followed by the motivations inducing companies to address energy efficiency.

Identified barriers and drivers to energy efficiency

Financial barriers to energy efficiency are often mentioned in earlier research. Technologies that are energy efficient are often more expensive to purchase than are alternative technologies. Moreover, obtaining additional capital to invest in energy-efficient technology may be problematic (Thollander et al., 2010). Energy-efficiency goals are often secondary to economic considerations. The initial cost-premium barrier causes developers and investors to hesitate to adopt sustainable investment practices (Lindkvist et al., 2014). Apart from low liquidity, limited access to capital may also arise due to restrictions on lending money (Hirst & Brown, 1990). Even if energy performance raises the asset value of a building, it is still not easy to show this increased value to possible buyers or renters/tenants (Baek & Park, 2012). A split incentive may occur when the potential adopter of an investment is not the party that pays the energy bill (Melvin, 2018; Palm et al., 2020; Thollander & Palm, 2013).

Governments can act by increasing the cost of inaction, punishing companies or discouraging them from not acting to improve energy efficiency (Peel et al., 2020). Government support such as investment subsidies has proven to be an important driver (Peel et al., 2020; Solnørdal & Foss, 2018). Another identified motivational factor is access to capital within a company or whether attractive energy loans are available. Another driver is whether the investment cost of energy-efficient solutions is perceived as low (Solnørdal & Foss, 2018) and whether a measure has a short pay-back time (Mata et al., 2021; Palm & Reindl, 2018). Other drivers are the potential for high savings from reduced energy use or the prospect of future energy cost savings, i.e. higher expected future energy prices might justify investments in energy-efficient solutions (Peel et al., 2020). Financial factors can thus work both to hinder and motivate energy efficiency, as illustrated in Fig. 1.

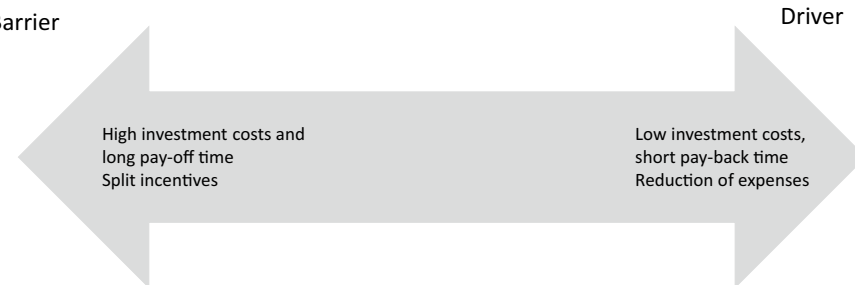

Fig. 1 Financial factors driving or hinder energy efficiency

A lack of compulsory standards or targets for energy efficiency due to low government interest in energy efficiency as well as changing and unpredictable regulations and schemes can be barriers (Labanca & Bertoldi, 2018; Peel et al., 2020). For example, if there are no regulations for how much energy a project can consume, the contractors must set their own limits for energy use (Englund, 2015); there is then no external pressure on contractors to change old habits. National policy can also motivate the industry by introducing compulsory standards, see Fig. 2.

Lack of information or imperfect information about existing measures can constitute a barrier. One example is in relation to the containers at construction sites, which consume a high amount of energy. There is a market for energy-efficient construction containers, but there is a lack of knowledge of their existence (Nakos Lantz, 2020). The cost of information, i.e. the cost associated with seeking and acquiring information about existing energy-efficiency measures, can also be high and inhibit awareness of potentially relevant energy-efficient solutions on the market (Thollander et al., 2010). Difficulties in communicating knowledge and in transforming information to knowledge are important barriers to conquer (Palm & Backman, 2017). An important driver related to information is the introduction of improved energy-efficiency measures in routines and processes. Lack of transformation pressure, aversion to change and path dependency together with lack of learning are however often-mentioned barriers (Palm & Reindl, 2018; Persson & Grönkvist, 2015). Training and education can on the other hand motivate staff and managers to transform and invest time and resources in improved energy-efficiency measures (Hampton, 2019; Mata et al., 2021; Palm, 2009; Peel et al., 2020; Solnørdal & Foss, 2018). Previous experience of energy-efficiency solutions is beneficial and a driver when it is reused in new projects (Mata et al., 2021; Palm & Reindl, 2016). Relatedly, loss of knowledge and skills between projects can be a barrier (Peel et al., 2020; Stafford et al., 2011). This loss of knowledge is related to the fragmentation of the construction industry, which involves many different actors working together in temporary coalitions. These diverse actors with varied interests can themselves constitute a barrier and inhibit learning (Häkkinen & Belloni, 2011; Lindkvist et al., 2014; Sorrell, 2003). Construction projects can be described as temporary coalitions of firms working together through subcontracting, which may complicate a common goal orientation at a construction site (Palm & Reindl, 2018; Sorrell, 2003). Networking and increased dialogue through actor networks in the sector can however be a driver of improved energy efficiency in the sector if used to clarify, analyse and communicate, for example requirements. Information hubs and the existence of industrial networks for sharing experience and raising awareness of energy-efficiency measures have proven successful in increasing companies' interest and engagement in energy issues (Butturi et al., 2019; Durand et al., 2018; Palm & Backman, 2017; Peel et al., 2020; Solnørdal & Foss, 2018). Dialogues and networking also benefit creative processes and innovation (Lazoroska & Palm, 2019; Palm & Backman, 2017; Westerlund et al., 2014). See Fig. 3 for a summary of the drivers and barriers in relation to information and networks.

The organisational culture and climate can be both drivers or barriers to energy efficient procedures and behaviour (König, 2020). Interaction between departments, the involvement and active participation of key stakeholders and qualitative information available in the organisation can foster energy efficient behaviour and routine. Relatedly, loss of knowledge and skills between departments can be a barrier (Peel et al.,

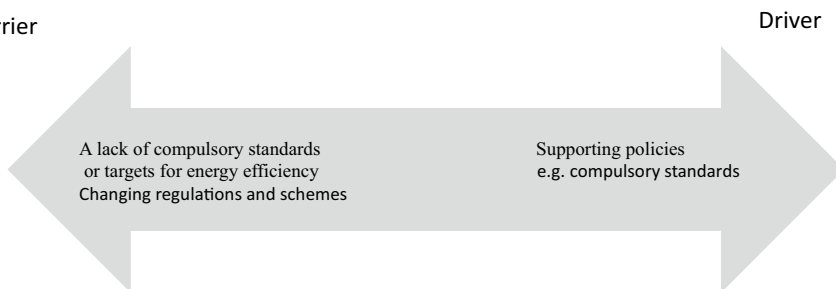

Fig. 2 Policy and regulations driving or hinder energy efficiency

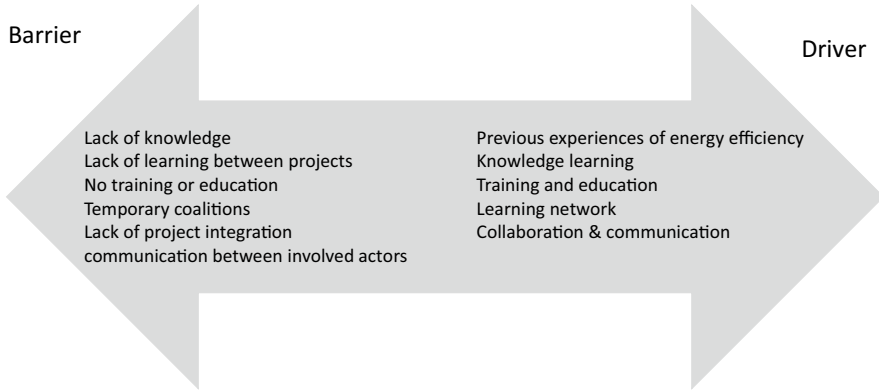

Fig. 3 Information and networks as barriers and drivers to energy efficiency

2020; Stafford et al., 2011). A handbook compiled by employees committed to working in line with certain guidelines can motivate changed behaviour (Almqvist et al., 2010). To further motivate energy-efficient behaviour, companies can provide their workers with information about their energy usage, comparing them with one another and with workers in other companies. This will encourage workers to decrease their own energy use (Nakos Lantz et al., 2021).

Another organisational driver is a desire to brand the company as sustainable and energy efficient. A company can also have a yearly goal of reducing energy use, which will encourage investments in improved energy efficiency. Having a motivated person—an energy champion—within an organisation has also been shown to be an important driver (Johansson & Thollander, 2018; Lazoroska & Palm, 2019; Palm & Thollander, 2020; Peel et al., 2020; Thollander & Palm, 2015, 2013). When there is market-driven demand for energy efficiency, for example customers demanding low energy use in the production process, this has proven to be an important driver (Mata et al., 2021; Solnørdal & Foss, 2018; Thollander & Palm, 2013).

Individuals and organisations are, in part, creatures of habit and established routine, which inhibit change in behaviours and habits. Contractors' and suppliers' lack of time to prepare a project together with their low profit margins and tendency to reuse solutions from previous projects, with only slight modifications (Sorrell, 2003), can contribute to an ongoing neglect of energy efficiency. There is a tendency to maintain current practices (Ahn et al., 2013; Palm & Reindl, 2016; Sorrell, 2003). Project timeframes also constitute a barrier, and projects with short timeframes will likely have little time for developing energy-efficiency strategies, as well as tighter budgets (Englund, 2015). Figure 4 shows identified barriers and drivers in relation to organisation and market.

Existing technology and products can be or be perceived as incompatible with new energy-efficient measures. A barrier can emerge if there is no universal solution and there is a need for individually designed energy-efficiency measures that could disrupt the construction

Fig. 4 Organisation and market factors as barriers and drivers to energy efficiency

process (Mata et al., 2021; Peel et al., 2020; Thollander & Palm, 2015). Related to technology, evaluating the use of installed technology and monitoring the technology to better understand its performance are additional identified drivers (Peel et al., 2020). Other motivational factors are technological solutions and product enhancement (Solnørdal & Foss, 2018).

Simply calculating and measuring the performance of specific technical equipment and how it can be more energy efficient in use have proven to be important drivers of energy efficiency (Xie et al., 2018). Measuring energy use is often mentioned as a way to identify 'energy thieves', leading to further actions; however, many organisations and companies do not know how to measure their energy use due to the lack of access to appropriate equipment (König, 2020). It is beneficial for the improvement of energy efficiency when clients specify demands that are performance based, measurable, monitored and maintained throughout the construction process (Häkkinen & Belloni, 2011).

Converting electricity heating to district heating is the most efficient way to reduce electricity at construction sites, according to several authors. Bergqvist and Smedberg (2017) discussed the problem that district heating must be installed before project start, and that it can only be installed if the project is located in an area where there is already a district heating grid. Figure 5 summarises technological barriers and drivers to energy efficiency identified in earlier research.

Methodology

As energy efficiency at construction sites is under-researched, this article explores the barriers to and drivers of energy-efficiency measures identified in earlier research, in combination with how practitioners perceive these barriers and drivers. The study started with a review of existing research and grey literature on the topic. The literature review was conducted using the keywords 'construction site' AND energy, 'energy use', enabler/motivation/driver, barrier/problem AND 'construction site'/'energy efficiency'. The search was conducted in Scopus, Web of Science and Google Scholar. The findings of these reviewed studies were presented above.

Interviews were done with professionals working with energy efficiency at the construction sites, focusing mainly the clients and the contractors. The property developer is the organisation that carries out the construction work or has it carried out. It can be a company, a real estate company, a municipality, a housing association or a private individual. The property developer is primarily responsible for ensuring that the construction work complies with the relevant regulations. The contractors are those who are responsible for the construction of all or part of the building. The most common is that the property developer hires a general contractor who handles the entire construction process or parts of it and the property developer is the client. The client can make requirements regarding energy at the construction site such as renewable electricity should be used and that the energy use should be measured. The contractor can also work with their own instruction on how to work to reduce energy use on the construction site (Nakos Lantz & Edenhofer, 2021).

Semi-structured interviews were conducted with different organisations where one had the role of clients, six had the role of contractors, one represented a rental company, and one was an independent consultancy working with energy efficiency at construction sites. In total, twenty people were interviewed in those nine organisations. Most of the interviewees were site managers or sustainability/environmental specialists

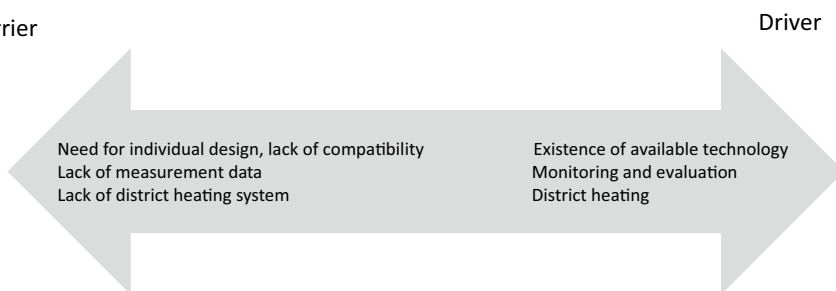

Fig. 5 Technological barriers and drivers to energy efficiency

or managers, a few were business managers or the like, and some were coordinators of various matters. The interviews took place on site in autumn 2021 and online when this was impossible. The project started in collaboration with a property developer in order to study one of their projects in Malmö. We soon realised that we needed to widen the study's scope to include more property developers and contractors with an interest in energy efficiency at construction sites, to broaden our understanding of relevant barriers and drivers. By using snowball recruiting and contacting existing industry networks such as LFM30 in Malmö, we found more interviewees. However, finding actors who actively work on energy efficiency at construction sites was difficult, so we finally also included those who had not yet actively taken measures but were interested in starting to address the issue.

An interview guide defined the overall structure of the interviews. The topics covered were interviewee background, information on company type and company goals (regarding the environment and energy). We further asked how and to what extent energy efficiency was addressed by the company, including in its various construction projects, and what barriers to and drivers of energy efficiency the interviewee perceived. Each interview also included specific questions tailored to the interviewee's specific roles and jobs (Kvale & Brinkmann, 2009).

We promised anonymity to the interviewees, so we do not attribute the presented quotations to named interviewees and do not name any of the represented companies. All interviews were recorded and transcribed. The interviews were analysed using the qualitative data analysis software NVivo. We conducted a qualitative content analysis (Hsieh & Shannon, 2005; Schreier, 2012) in which barriers and enablers were defined both inductively and deductively. The validity of the study is supported by data triangulation, i.e. the use of multiple data sources and respondents (Maxwell, 2005).

Results

The results of the interview study are presented below, are organised according to the barriers and drivers identified in earlier studies, starting with the financial barriers and drivers, followed by policy and regulations, information and networks, organisation and markets and finally technology.

Drivers and barriers in relation to financial aspects

Financial issues were described and discussed in many different ways in the interviews. One common comment was that there was often insufficient money in the project budget to finance energy-efficiency measures. On the other hand, interviewees also said that money was instead cited as an excuse, and that it was really a matter of priorities.

The respondents had several ideas about what could be done to improve energy efficiency and/or increase the use of renewables. A recurrent topic was installing solar panels on the construction container or connecting solar panels to the crane:

> We tested this. It is on only one of the containers that we have installed [solar panels] in this first phase, and then we will see how this works out, whether this is something to develop in coming projects. And it could supply one fifth of the power needed for the construction container. (Interviewee 16, contractor)

A construction site is special in that it exists for only a short period, such as 1 to 2 years. A barrier then arises in connection with pay-off time and how to calculate the costs and benefits of, for example a solar panel or an investment in more energy-efficient tools or machines. Several raised the conflict of trying to calculate the installation cost of something that is supposed to be used for 30 years, but that in practice is only used for 1 or 2 years, at least at one site. The lack of standards and procedures for calculating these investments made it difficult to demonstrate the cost-effectiveness of these measures. The bigger the project, the easier it was for the actors to demonstrate cost-effectiveness:

> But we have installed photovoltaics on the construction containers. And to be honest that is more for marketing, to show that we have them. Really reducing the energy consumption requires more roof area than the containers have. It might be better to reflect on how the electricity we buy is produced. (Interview rental company)

A barrier several experienced was split incentives: as the clients did not pay for the electricity, they were relatively uninterested in the issue. Many believed that if the clients were the ones paying, they would demand higher energy efficiency. The vast majority of respondents argued that the construction clients were responsible for driving the question of energy efficiency forward. Energy efficiency was described as demand driven, and it was up to the clients to require improved energy efficiency.

Another barrier mentioned was that the electricity was too cheap, making it not worth the effort to develop energy-efficiency strategies. A common argument was that if the electricity were more expensive, both clients and construction companies would value and prioritise energy efficiency more highly.

Energy-efficiency measures might have high short-term costs, for example for buying new equipment, installing solar panels or hiring special competence. However, those actively working on these measures were aware of the resulting long-term savings, and for them saving money was an important driver. Many respondents also stressed the competitiveness that resulted from incorporating energy efficiency considerations in a project. More and more clients were becoming aware of environmental issues, and the interviewed construction companies noted a trend in which clients had started to demand that construction companies address energy-efficiency goals. Interviewees believed that construction and hiring companies in the forefront of providing energy-efficient solutions would likely start benefitting from this in the procurement process. The respondents expected a higher future demand for energy efficiency on the market, which would benefit those that started the transition early. A common comment was that the more demands the clients make, the more motivated the companies are to develop energy-efficiency strategies.

Policy and regulations

A lack of regulations or clear regulations was seen as a barrier by several of the respondents. Although they could see that there were many ways of encouraging companies and clients to work on improving energy efficiency, there was agreement that regulations were the best way forward. However, too many regulations could have the opposite effect, as one respondent argued:

> There cannot be too many rules and [it cannot] take too long to get permission. /,,/ When we want to connect photovoltaics to the grid, there are many rules – and of course, there must be regulations because it is related to safety – but you must create opportunities and not just impose regulations that hinder us from utilizing existing opportunities. (Interviewee 16, contractor)

According to some respondents, the environmental standards and requirements related to specific certifications, such as BREEAM and LEED, were the only efficiency demands most clients made. Those certifications did not cover the construction site, however, as the criteria were assessed only in relation to the final product. Even so, this seemed to motivate the construction companies to improve their energy efficiency also at the construction site:

> Customer requirements in the form of environmental certifications, that is what motivates us to make an extra effort. (Interviewee 12, contractor)

A general reflection concerning the motivation for and drivers of improved energy efficiency at construction sites is that the interviewees became vaguer and more speculative in their responses versus when barriers were in focus. When the interviewees discussed drivers, it was often in terms of potential rather than actual drivers. In line with this, several respondents said that 'better regulations' had the potential to be an important driver. They believed that a regulatory push and clear guidelines would motivate companies to address energy efficiency. Existing policy instruments that did function as motivators were the various environmental certifications, which, as discussed above, also incentivise the construction sites even though they strictly apply only to the completed building:

> When the buildings are completed there are regulations that force us to focus on energy efficiency – the legislation has gone further in that area. We can build zero-energy houses and energy-positive houses without hesitation. (Interviewee 1, contractor)

Information and networks

There was agreement among the respondents that there was either a lack of knowledge or a lack of knowledge transfer concerning energy efficiency in the construction industry. One reported barrier was that it was difficult to know where to start, to know what energy-efficiency measures to prioritise. There was also a lack of knowledge of energy-intensive activities and equipment and of what methods to use to reduce the energy needed for specific activities. Several respondents said they wanted to work more on energy efficiency but did not know how. The site managers said they needed to develop their own processes and routines to improve energy efficiency at the construction sites:

> We learn a lot from previous experience, learning by doing. Some stuff works well and other stuff less well, but I don't have any educational experience in energy efficiency. That would be useful for the construction industry, to collect knowledge from the industry to share. I probably have some knowledge to share, as well as something to learn. (Interviewee 7, contractor)

For example, some respondents lacked information about energy-efficient construction containers available on the market. In the case of construction containers, some rental companies offer packages including different categories of energy-efficient construction containers, but this information did not reach the site managers. Consequently, interested site managers developed their own solutions to improve the energy efficiency of the containers, such as covering gaps in the wall to prevent heat from escaping.

A driver of information diffusion was participation in industry networks in which actors from the construction sites collaborated to achieve ambitious sustainability goals. Networks can be used to transfer knowledge about energy-efficiency tools and about the potential energy-related demands in projects. Being part of a network provided companies with tools, frameworks and templates that acted as drivers when setting energy-efficiency goals or testing different methods to see what worked for them. Many respondents believed that these collaborative networks were an upcoming trend, with great potential to become a driver.

Many also mentioned that the electricity utility company had the potential to play a more important role by providing more information about energy consumption patterns, flexibility and demand-response:

> They have all the data, they can see where the highest energy use comes from and what time of the day. They should analyse the highest energy use, and we can together develop measures to decrease this. Make contact with us for dialogue and we can together find ways to decrease the peaks. (Interviewee 14, contractor)

An important driver related to this was the existence of internal education, which was in place in some companies and had raised awareness of the potential for greater energy efficiency. Another driver reported in the interviews was that companies possessing knowledge in the field of environmental sustainability tended to prioritise energy efficiency higher than did those without such knowledge. In companies lacking both knowledge and information about energy efficiency, energy-efficiency measures were also perceived as more costly and time consuming than business as usual, versus in companies claiming to be informed about energy and environmental issues.

Organisation and market factors

The conservatism of the building sector was often discussed, and most respondents upheld this view and described the construction industry as conservative. It was considered difficult to change an established procedure; one interviewee said, for example:

> You do as you always have until someone forces you to change. And there is no one who forces you to do anything differently. (Interview rental company)

Another interviewee said that the industry must come together to change its behaviours and attitudes:

> I don't think that the industry is really there, they're lagging behind – everything from construction container rental companies to lighting. We're not quite there yet, which contributes to higher costs and hence lower incentives. The industry must wake up and we need to improve our knowledge. (Interviewee 9, Client)

There was also another perspective, with one respondent claiming that environmental issues were being prioritised and that most companies were transforming themselves to become more energy efficient, but that they were slow to get started. The top-level management in the organisation was working on energy-efficiency strategies, but it was difficult to apply these to the projects.

Another mentioned barrier was that energy-efficiency measures depended on the site managers. For this reason, the problem of implementing energy-efficiency measures became an individual question of whether there was a local champion at the construction site interested in energy and sustainability issues:

> Some site managers are very energetic and very aware … when it comes to questions like these, while others are less. The level of energy-efficiency work is dependent on the site manager, which means this person must have an interest of it. (Interviewee 15, contractor)

Another barrier was the lack of suitable site managers, so that even if a company had developed energy-efficiency strategies, they would have difficulties implementing them if the site manager was sceptical about energy efficiency. The representative of a rental company had many experiences from companies that were afraid of losing sceptical site managers if they enforced implementation:

> To some extent, we do have solutions whose positive effects are obvious and that are ready to use in all our projects. The problem is that there is a great lack of site managers in the construction industry, so the employer doesn't dare be too strict. As soon as you make demands, you face the risk of people violating them, and must be prepared to take action against this. This can be unpopular among the employees, who can then easily look for another job. (Interview rental company)

The common belief among respondents was that the energy issue needed to be a higher top-management priority, and that this was a key issue in achieving improved energy efficiency at construction sites.

One company described internal competitions between projects as a driver of behavioural change: different construction projects competed to be the most energy efficient. This had proven to be a successful driver, encouraging both the workers and site management to start reflecting on energy consumption and how to improve energy efficiency in their daily routines. The best performance was rewarded with points that were shown on the company's intranet:

> The winning team gets extra attention at our intranet. Many of us are competitive, which makes it extra fun to get that attention. (Interviewee 16, contractor)

Several respondents found that it was hard to ask colleagues to close doors or windows to prevent heat loss, noting that 'carrots' and encouragement had better potential to change routines.

Site managers' attitudes towards energy efficiency were repeatedly mentioned as an essential driver or barrier, depending on if the person was negative or positive. Often this was seen as the single most important factor determining whether or not the construction site would prioritise energy efficiency. In one company in which energy efficiency was highly prioritised by top management, the site managers and teams with a good track record of successfully implementing energy-efficiency measures were allocated energy-intensive projects. These site managers with good track records were cited as good role models, with the idea that their attitude would spread to others, driving them to address energy efficiency as well. For the construction company, this driver showed that they had teams that could meet the ambitious demands of clients.

Bigger companies with back-office functions described these as a driver, in that they could provide employees with knowledge and information as they often have special competence such as environmental specialists or sustainability heads. Some bigger construction companies had internal policies and routines for how to address energy efficiency in the construction phase, which also became an important driver of energy efficiency at the sites.

Some companies had set aside resources for research on energy efficiency, to find new methods and tools. One studied company had a special unit for energy-efficiency research and education. The resulting knowledge was actively transferred throughout the company, and this was seen as an important driver of the company's reputation as successful in both energy efficiency and sustainability in general. Another important driver mentioned was the use of checklists of energy-efficiency measures,

including energy-efficiency tools and guidelines on how to use them. Some companies, but not all, have clear regulatory documents for how to address energy efficiency and contribute to knowledge transfer:

> We have our project database with economic systems and regulatory documents and maps of processes, etc. And it's simply the regulatory documents that direct us. We follow them, and that's really where we get the best knowledge transfer. Partly through meetings and information, but also because we are implementing the solutions … we get from the regulatory documents. We get automatic knowledge transfer, and that is really the best way of doing it, I think. (Interviewee 5, contractor)

Several interviewees came back to a driver not discussed in earlier research, which was to have an energy-efficiency plan. If the project was planned properly, seasonal variation could be one factor considered:

> From a broader perspective, it is more relevant when a project is started to put the more energy-critical moments in place based on the season instead. Then you can really save some energy, then the effort will become profitable. (Interviewee 2, contractor)

If energy efficiency was planned for, this also entailed searching for existing information and earlier experience before starting the project. Planning for energy efficiency in projects also meant that, for example rental companies were included in dialogues at an earlier stage than was usual, to have them provide solutions for energy-efficient logistics and equipment that benefitted energy efficiency at the construction site. Planning for energy efficiency was something several companies had started to reflect on, but none had implemented.

A final driver in this category was client demand, and a common view was that when clients knew more about the importance of energy efficiency, they also made higher energy-efficiency demands in their projects. This implies that information and knowledge transfer are important drivers.

Technological barriers and drivers

In general, the interviewees did not consider technology to be a barrier to energy efficiency. Measuring electricity use at construction sites was, however, an untapped potential that would improve the understanding of energy-intensive processes and of where the 'low-hanging fruit' is. One respondent said that one barrier was that each project was unique, so measurements from one project would differ from those from another. If resources are spent on measuring, they need to be combined with other measures such as developing processes for knowledge transfer between projects.

Tools and employees specialising in energy mapping were mentioned by several respondents as important drivers of energy efficiency. Some companies already possessed both tools and skilled staff, but some interviewees discussed these more in terms of unrealised potential. Several company representatives did say that they did not know where to start working on energy efficiency but believed that energy mapping was a good way to start. When discussing the construction containers, the interviewees said that an important driver would be for the rental companies to offer energy-efficient containers. Some also highlighted the need for a clear classification system for the containers. However, there was also a knowledge gap, in which the interviewees did not have an overview of the existing market and a classification system for containers was about to be implemented. This could become an important driver in the future, but for this to happen, the construction companies would need to become informed about available solutions and plan for them early in the project process. The rental company meant they needed to be involved early in the process to be able to influence:

> We have noticed that we have many good solutions … we just need to be involved earlier in the process, already in the planning stage. When the time plan and budget are set, it's too late and we cannot provide the most optimal solutions. (Interview rental company)

Many respondents talked about solar panels as an upcoming technical driver of energy efficiency—or at least as a driver reducing the amount of purchased energy. Although these respondents had not investigated how to implement PV solutions and knew that

the short-term costs of solar panels were high, several believed that solar energy would be a leading driver of the transformation to a more sustainable construction industry.

Discussion

The data collected have been analysed in relation to barriers and drivers. Few earlier studies have examined improved energy efficiency at construction sites; in view of this, we applied an explorative approach and asked open questions to the interviewees about perceived barriers and drivers. The barriers and drivers identified were therefore not ranked. It was noticeably easier for the interviewees to identify barriers rather than drivers. When the interviewees responded regarding drivers, it was often in terms of potential rather than existing drivers. This could be because energy-efficiency work at construction sites is still in an early phase, and most companies have yet to develop suitable strategies.

All interviewees discussed different key actors important for achieving improved energy efficiency at construction sites. In general, the interviewees identified another actor than themselves as the key actor. One such key actor was the government, and there was a desire to have compulsory standards and incentives in the form of support programmes. Earlier research has also identified the government as an important actor in improving energy efficiency in companies (e.g. Peel et al., 2020; Solnørdal & Foss, 2018). According to the interviewees, government action would promote energy efficiency as a priority among all actors and speed up the transition. Another identified key actor in improving energy efficiency was the site managers, who seemed reluctant to assume this role. A way forward could be to prioritise them for education and information dissemination. Another key actor identified in earlier research and by our interviewees is the company's top management (Thollander & Palm, 2013, 2015). The interviewees believed that the top managements of both clients and contractors were important and needed to start demanding improved energy efficiency. Especially the role of the clients was emphasised: if they started to demand improved energy efficiency, this would also spur interest in the issue by the contractors (compare, e.g. Solnørdal & Foss, 2018; Mata et al., 2021; Thollander & Palm, 2013). A major energy-efficiency issue at construction sites might therefore not be what should be done, but rather who should be responsible.

An often-mentioned barrier was lack of knowledge and difficulties finding and diffusing relevant information. Being part of an industrial network is a well-established measure found to be successful in earlier studies (e.g. Backman, 2018; Borg & von Knorring, 2019; Köwener et al., 2011; Palm & Backman, 2017) and that seems to be applicable in this case as well. Several interviewees mentioned network collaborations as import for diffusing knowledge and information. These networks are also important opportunities to become informed about what demands can be made in a project.

Most interviewees mentioned the importance of compulsory standards in supporting the energy-efficiency transition. Clients work with different standards, and these can sometimes spill over and influence what is happening at construction sites, even though the construction site is not directly addressed in these standards. The lack of standards directly targeting energy efficiency at construction sites was mentioned as a missed opportunity and potential important driver if such standards could be developed.

Energy audits and energy monitoring were lacking at construction sites, although many companies had started to think about them. There was consensus that these were important tools that would improve our understanding of the existence of 'energy thieves' and of where to implement energy-efficiency measures or change routines. The interviewees requested energy-monitoring tools, which could be a starting point for introducing more information about energy efficiency. This was a rather surprising result. Considering that demand-response is a well-established practice in the building sector, where monitoring and control are essential (e.g. Albadi & El-Saadany, 2008; Bartusch et al., 2011; Good et al., 2017), this could be expected to spill over to construction sites, but it had not. The actors believed that mandatory audits and monitoring were the way forward, but there was reluctance to take the lead in this development. This reluctance to be at the forefront and be a change agent has also been noted in earlier research (e.g. Palm & Reindl, 2018; Persson & Grönkvist, 2015). This reluctance existed even though everyone agreed that the companies taking the lead in improving energy efficiency would gain from it, because increased

demand for improved energy efficiency was expected in the near future. This lack of champions in the area could be because of split incentives (Melvin, 2018; Palm & Backman, 2020) and because the one making an investment is not always the party that pays the energy bill.

Lessons learned from the companies that did work on energy efficiency at construction sites were that incentives seemed to work better than compulsory measures, and that an effective way of encouraging transition was to start a competition between construction sites and then internally monitor it continuously. The latter approach has also been discussed in earlier research (see, e.g. Trianni et al., 2016).

Many of the above-mentioned barriers come back to the need to prioritise energy efficiency. With the many issues and actors involved at a construction site, energy efficiency faces the obvious risk of being forgotten. There is a need to pay attention to energy from the start of planning a construction site to the very end of the project when the construction site ceases to exist. The material indicates that planning for energy efficiency was crucial for having it considered at the site. If energy efficiency is not planned for, it is difficult to include it in a later phase. Information and experiences from earlier projects need to be collected, energy-efficient equipment and tools ordered, and new routines and behaviour established before entering the construction site. When the construction site is already in place, it seems difficult to make changes. This makes advance planning essential to success in improving energy efficiency, which justifies considering it a category in its own right.

Conclusions

The aim of this research was to investigate the barriers to and drivers of energy efficiency at construction sites. The identified financial barriers were related to lack of money and that there was no money set aside for energy efficiency. Another arising from the combination of short projects and long investment pay-off times resulting in split incentives, where the actors paying for energy efficiency were not the same that benefit from the reduced electricity bill. A barrier was that energy efficiency measures have high short-term costs, which make an energy efficient project less competitive. A related barrier was the lack of standards and procedures for calculate energy efficient measures, which made it hard to demonstrate cost-effectiveness in the long run. A barrier at the time for the interviews was low electricity prices, a barrier that effectively seems to have been removed by the Ukraine war resulting in that the price for electricity increased. A potential financial driver identified was a support scheme to push the market.

Lack or regulations were seen as a barrier, while regulations forcing actors to implement energy efficiency was mentioned as a potential driver. Another driver was environmental and building certifications such as BREEAM. A barrier in relation to the building certificates was however that they did not cover the construction site but only the final product.

Lack of knowledge and information about energy efficiency were seen as a major barrier. There was a lack of knowledge sharing and there were no arena or platform where the actors could share good and bad examples. A driver was on the other hand to be part of an industry network where knowledge on energy efficiency was shared. Another related driver was the existence of internal education. A potential driver mentioned was an engaged electricity utility company providing information.

A barrier often mentioned was the conservatism of the industry, making it difficult to change behaviour and routines. When the top or site management was working with energy efficiency this became a driver, but when their support was lacking it was a barrier for improved energy efficiency. A driver encouraging energy-efficient behaviour and routines were competitions between construction sites. The existence of a plan, checklists or project database was also seen as an important support of energy efficient routines. When a company had a back-office supporting with information and advice on energy efficiency measures, this was also seen as a crucial driver. Another essential driver was client demand of energy efficiency. Technology, together with tools and employees specialising in energy mapping, was in general seen as a driver.

Figure 6 summarises the barriers and drivers identified in this explorative study.

As mentioned above, research on energy efficiency at construction sites is still in an early phase, and further research is needed that includes more data. The barriers and drivers identified in this explorative study can be used as a basis for a questionnaire targeting

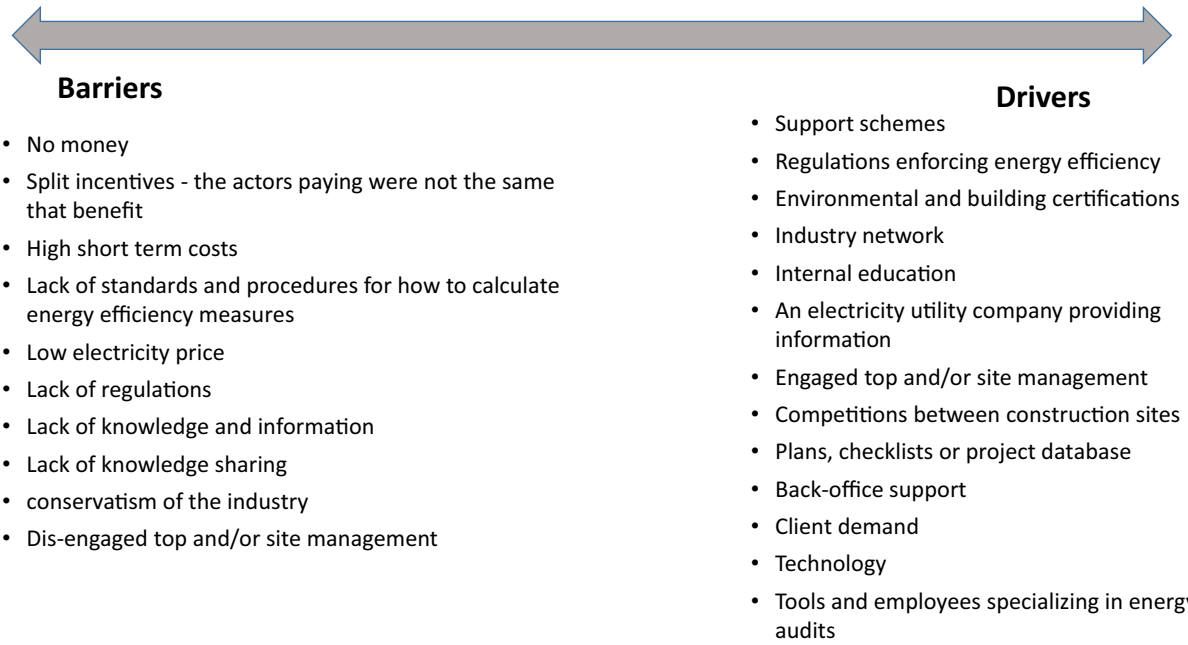

Fig. 6 Barriers and drivers identified in the study

different actors involved in construction sites, to enable statistical analysis of the barriers and drivers that the actors perceive. Future studies could also examine individual barriers and drivers to deepen our understanding of, for example why there is a lack of energy monitoring at construction sites or how big an effect competition between construction sites can have on energy use.

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Declarations

Conflict of interest The authors declare no competing interests.

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