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Neglecting exit doors: How does regret cost shape the irreversible execution of renewable energy megaprojects?

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ABSTRACT

The energy transition process nowadays is characterized by the replacement of fossil fuels-based means of production with renewable energy (RE). Alongside the diffusion of decentralized RE, this process is associated with the increased promotion of RE megaprojects. Such megaprojects, however, are often shaped by path-dependent lock-ins and thus continue to be promoted with limited changes despite the emergence of better alternatives along the way. This study explores the role of lock-ins in the irreversibility of RE megaprojects while highlighting the notion of regret cost. In particular, the study sheds light on the influence of lock-ins within megaprojects, specifically focusing on their execution stage. Using the establishment process of Ashalim, a giant thermal solar power station in southern Israel, as a case study, we demonstrate how various lock-ins increase regulators' regret cost, thus escalating their commitment to the megaproject and causing them to neglect diverse "exit doors" during execution. We thus illuminate the irreversibility of RE megaprojects and question their capability to meet the growing need of energy markets for flexibility.

1. Introduction

The energy transition process that is currently underway entails the promotion of renewable energy (RE) megaprojects, alongside decentralized RE, which replace large-scale fossil fuel-based means of production (Irena, 2020). Literature regarding energy transition has discussed extensively the significant contribution of RE megaprojects to tackling climate change, emphasizing the large amounts of clean and sustainable energy that they can provide (Dai et al., 2016; Gutierrez et al., 2019; Nelson et al., 2013; Sovacool and Geels, 2021).

By nature, megaprojects are either very good or quite bad: studies have found that 35% of megaprojects are excellent in terms of budget and time frame, while the other 65% have an average of 40% budget overrun and 28% time-slippage (Merrow, 2011). Therefore, the process of designing megaprojects, which influences their execution stage, is very important: indeed, scholars have discussed at length the concept of stage gate reviews: structured milestones that offer opportunities to recycle back, to continue, or to

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cancel/postpone megaprojects during their design process (Flyvbjerg et al., 2003; Merrow, 2011; Barshop, 2016). These reviews, therefore, aim to increase the flexibility of megaprojects, thus enabling changes along the way. Such flexibility is especially important in RE megaprojects because they should provide energy markets with new opportunities and degrees of freedom through technological improvements, enhanced sustainability, increased efficiency, and decreasing costs over time (Irena, 2018; Ren21, 2019).

Nevertheless, despite the existence of stage gate reviews, evidence indicates that megaprojects, and RE megaprojects in particular, are often characterized by limited flexibility (Callegari et al., 2018; Nasirov et al., 2018; Van de Graaf and Sovacool, 2014). This is often the result of various lock-ins stemming from path dependencies (Fouquet, 2016; Hetemi et al., 2017, 2020). Path-dependent lock-ins (Fouquet, 2016; Hetemi et al., 2017, 2020) are understood in this study as how "one path becomes dominant due to self-reinforcing processes and absorbing states, and this causes the economy to lock itself in to an outcome which is not necessarily superior to alternative ones, not easily altered and not predictable in advance" (Arthur, 1989, p. 128). Lock-ins enhance what we refer to as "regret cost," i.e., they increase the "price" that regulators must pay to execute policy changes along the way (Bohringer and Rutherford, 2015; Leib and Buckle, 2012; Leijten, 2013; Priemus, 2008). Shaped by various lock-ins, the regret cost may escalate regulators' commitment to various megaprojects (Sleesman et al., 2018), often leading to suboptimal outcomes (Drummond, 2017; Flyvbjerg, 2009; Priemus, 2010; Söderlund et al., 2017).

Thus far, literature regarding energy transition has mostly discussed lock-ins through the prism of the "carbon lock-in," which describes the self-perpetuating inertia created by large fossil fuel-based energy systems, inhibiting efforts to introduce alternative energy technologies, most notably RE (Unruh, 2002). RE systems, by contrast, are often depicted as a more malleable option, and the transition literature has so far failed to thoroughly explore the influence of lock-ins in this context (Katre and Tozzi, 2018; Newcomb et al., 2013).

Our study aims to address this research lacuna by empirically demonstrating the role of path-dependent lock-ins in the context of RE megaprojects, specifically focusing on the notion of regret cost. To explore the role of lock-ins in RE megaprojects, we apply a case study approach (Yin, 2003), exploring the planning and construction process (2007–2018) of the Israeli "flagship" RE megaproject—the thermal solar power station of Ashalim—which constitutes a good example of an irreversible megaproject. Based on this case study, we demonstrate how various lock-ins shaped the course of events in the establishment of the Ashalim megaproject. In this case, the escalation of the Israeli regulators' commitment led them to overlook several "exit doors" in the execution phase that could have enabled them to avoid the high costs of this megaproject by replacing expensive thermal solar technology with the cheaper PV solar technology. Hence, by unpacking the factors underlying the irreversibility of RE megaprojects, this study sheds light on the disadvantages of RE megaprojects, specifically under the conditions of technological uncertainty that characterize the rapidly changing energy market (Irena, 2018; Ren21, 2019).

This study contributes to the transition literature (Köhler et al., 2019) because the flexibility of RE is crucial in order to meet energy markets' need for continuous innovation, leading to rapid improvement of technology, increasing efficiency, and decreasing costs over time (Bayer et al., 2013; Chen and Lei, 2018; Elia et al., 2021; Saygin et al., 2015). The lack of such flexibility may, therefore, question the role of RE megaprojects in the energy transition process (Burger et al., 2019; Sovacool and Cooper, 2013; Yaqoot et al., 2016). The study also contributes to literature concerning megaproject management by addressing Hetemi et al. (2020) call to shift the exploration of lock-in emergence from 'what is wrong' to 'how' and 'why' it emerges. This is achieved by demonstrating the emergence of lock-ins within a specific RE megaproject (Cantarelli and Flyvbjerg, 2013) rather than examining their emergence between projects, as is common in the existing literature (e.g., Frantzeskaki and Loorbach, 2010; Klitkou et al., 2015; Nordensvärd and Urban 2015). This perspective yields another theoretical contribution, enabling us to demonstrate the emergence of lock-ins during the execution stage of megaprojects, and not only during the design stage, as the literature does at present (Flyvbjerg et al., 2003; Merrow, 2011; Barshop, 2016).

The paper continues as follows. The first section discusses the notion of megaprojects, focusing on the unique characteristics of RE megaprojects and the need for flexibility in their design. This is followed by an examination of how path-dependent lock-ins influence the escalation of commitment to megaprojects through the framework of regret cost. The next section outlines our methodology, which is based on a rigorous examination of primary documents. We then present the case study itself, using Ross and Staw's (1993) typology to demonstrate how different lock-ins increased regulators' regret cost and thus escalated their commitment to the Ashalim RE megaproject. This is followed by a discussion of our main findings and their contribution to the transition literature. Finally, the last section presents the main conclusions of the study and proposes a path for future research.

2. Accommodating flexibility into renewable energy megaprojects

In recent decades, scholars have taken increasing interest in megaprojects, used in the infrastructure, water, and energy sectors (Flyvbjerg et al., 2003; Merrow, 2011; Barshop, 2016; Van Marrewijk et al. 2016). They have suggested focusing on megaprojects as "complex social settings characterized by tensions between unpredictability, control and collaborative interaction among diverse participants" (Cicmil et al., 2006, p. 676). Megaprojects are non-routine, temporary endeavors that require special authorization, funding, revenues, and regulatory actions (Van Marrewijk et al. 2016). They are typically controversial, proceeding slowly and involving different electoral and business cycles for which public–private cooperation is needed (Scott et al., 2011).

RE megaprojects, a specific case of the wider phenomenon of megaprojects, provide significant amounts of clean and sustainable energy (Dai et al., 2016; Nelson et al., 2013), making them suitable substitutes for large-scale fossil fuel-based facilities as part of the global energy transition process (Gruenig and O'Donnell, 2016). Therefore, such projects are often viewed as symbols of economic power, energy independence, and technological progress (Dai et al., 2016; Gruenig and O'Donnell, 2016; Nelson et al., 2013). RE megaprojects may utilize a variety of technologies, including hydropower, wind, biomass, solar, and others (Schumacher, 2019). These megaprojects may require enormous space and are frequently connected to the transmission grid rather than the distribution grid (Gruenig and O'Donnell, 2016; Ryberg et al., 2018). Their enormous dimensions increase environmental concerns, which vary according to the specific RE technology, such as damage to the landscape, noise pollution, harming biodiversity, and disrupting water flow (Abbasi and Abbasi, 2000; Pasqualetti, 2011), or pushing aside local populations (Becker et al., 2017; Haf et al., 2019). RE megaprojects also require significant resources such as knowledge, finance, regulation adjustments, authorization, and land plots (Rad et al., 2017; van Wijk and Fischhendler, 2017), which are often provided by large private corporations (Gruenig and O'Donnell, 2016; Sovacool and Cooper, 2013). All these significant implications frequently lead to increased public sector involvement to centrally manage or synchronize the planning, design, approval, execution, and delivery process of such megaprojects (Eitan et al., 2020; Komendantova et al., 2012; Sovacool and Cooper, 2013; Van de Graaf and Sovacool, 2014).

Evidence indicates that many megaprojects, including in the RE field, fail to meet their assigned budget and time frame (Merrow, 2011). According to megaproject scholars, the problematic nature of megaprojects, and RE megaprojects in particular, does not stem from their establishment process itself but rather from the (low) quality of the planning and approval processes upfront (Flyvbjerg et al., 2003; Merrow, 2011; Barshop, 2016). At least three checkpoints, gate reviews, are built into the approval process to give sponsors the flexibility to stop or recycle a megaproject (Merrow 2011; Barshop, 2016). In the first gate review, the robustness of the business case is assessed. Recycling, which is the remitting of a project to an earlier stage, is not uncommon: indeed, about 15 percent of all projects are recycled at one of the gate reviews (Barshop, 2016). The second gate review, named select, evaluates if all scopes are completed, if the scope can be closed and prices the project. According to Merrow (2011) and Barshop (2016), these two gate reviews are very important but are often conducted with less rigor and discipline than the third gate review. The third gate review is authorization: the sponsor evaluates if the project is ready and prepared for execution and then gives its full commitment to the funds needed. The goal of the gate reviews is to focus on the most important investment opportunities, to maximize value, and to control financial and reputational risks. These reviews ensure that only the highest-priority projects are funded and that spending on projects that will ultimately not go forward is stopped at the earliest possible time (Barshop, 2016).

Frequently, RE megaprojects utilize innovative technologies. Merrow (2011) claims that one third of all types of megaprojects tend to involve the wholesale change of technologies. Using such innovative technologies creates high levels of uncertainty. Therefore, Priemus (2010) suggests postponing the choice of technology until the third gate review. If major changes must occur after the closing of shaping, the project is at risk of failing (Merrow, 2011). Therefore, flexibility in the stage gate process is extremely important. Cantarelli and Genovese (2021) found that project sponsors may fall victim to the risk of "technological sublime," an emphasis on using innovative technologies in megaproject delivery despite a higher level of uncertainty.

However, notably all the gate reviews described above take place in the design stage of the megaproject, during which decision makers search intensively for reasons to make a timely exit before the actual execution of a megaproject. Unsurprisingly, it is very unusual that a megaproject is canceled once execution has begun. Once started, project managers do not kill the project: "Nothing [can stop us], this project is going forward!" (Merrow, 2011). Sometimes however, megaprojects get stopped during execution. Juarez Cornelio, Sainati, and Locatelli (2021) present several examples of unfinished megaprojects, but they state that literature concerning these is limited. Resistance of citizens, lack of funding, and changes in the political context are the dominant reasons for abandoning or suspending a megaproject during execution (Juarez Cornelio et al., 2021; Gupta 2018). For example, the rise of a new Mexican government as a result of democratic elections resulted in the direct cessation of the building of the new airport near Mexico City (Juarez Cornelio et al., 2021). In another example, Gupta (2018) discusses the construction of the Narita Airport in Japan, which was suspended for almost 20 years.

Stopping or abandoning a megaproject, even after a stage gate review process, is expensive. Typically, much money has already been spent before authorization; assess costs 0.5% of the total cost, select 1.5%, and define 3% (Barshop, 2016). For sponsors, the money spent can grow so large that "canceling a project and generating a large chunk of sunk costs can be a very difficult decision to make" (Barshop, 2016, p. 123). Hence, despite the need for flexibility in the RE landscape, and the existence of various dedicated mechanisms such as stage gate reviews, it is often not possible to turn the clock back with regard to megaprojects, and RE megaprojects in particular. This may be the case during the planning stage of RE mega projects, but even more so during their execution stage. This brings us to the mechanism behind this lack of flexibility: lock-ins and their influence on RE megaprojects.

3. From lock-ins to regret cost

One starting point for understanding lock-ins is the concept of organizational path dependence. Lock-ins are commonly regarded as the final phase of organizational path dependence: in the preformation phase, many options are still available, in the formation phase the number of options is limited, and in the final lock-in phase, self-reinforcing dynamics bring about a single preferred action pattern (Sydow et al., 2009). The emergence of lock-ins, through the prism of organizational path dependence, has been specifically discussed in the context of megaprojects, in light of their temporary and inter-organizational nature. In this framework, Hetemi et al. (2020) describe how the lock-in mechanism in megaprojects is shaped by experience, embedded into the interorganizational network, and occasionally strategically manipulated by various actors. Alternative courses of action are no longer feasible in lock-ins due to high costs for switching or stopping, the sunk costs that have already been spent, and the possibly monopolistic position (Hetemi et al., 2020).

Mahoney and Schensul (2006) refer to the concept of path dependence lock-ins as the process via which past events or decisions constrain later events or decisions, often leading to suboptimal results that can no longer be avoided (Mahoney and Schensul., 2006). While the concept of a lock-in is often used to address path dependency between projects (Frantzeskaki and Loorbach, 2010; Klitkou et al., 2015; Nordensvärd and Urban 2015), we address lock-ins as a "within" project phenomenon: "The over-commitment of parties to an inefficient project before the formal decision to build is taken, and to the inefficient specification of the project after the formal decision to build has been taken" (Cantarelli and Flyvbjerg, 2013, p. 340). Based on this perspective, lock-ins may affect megaprojects at two levels: decision-makers may be committed too early in the stage of the design process, as well as after the decision to build the megaproject is made, making them unable to revise decisions regarding its features (Cantarelli and Flyvbjerg, 2013).

In this context, Ross and Staw (1993) identified four groups of determinants that can be referred to as lock-ins in the framework of megaprojects. The first is *project* lock-ins such as closing costs, salvage value, the causes of setbacks to its completion, and the economic and legal merits of pursuing or dropping it. The second, *psychological* lock-ins, comprises difficulties in withdrawing, need for self-justification, and attempts to recoup sunk costs. The third, *social* lock-ins, includes following expected norms related to social and cultural issues or the desire to justify projects to a diverse audience, while the fourth, *organizational* lock-ins, often relates to the level of political support and other structural or institutional pressures.

These different lock-ins have been employed to shape the escalation of commitment to megaprojects (Hetemi et al., 2020; Juarez Cornelio et al., 2021). Escalation of commitment is here defined as "the tendency to 'carry on' with such questionable endeavors, regardless of whether doing so is likely to result in success" (Sleesman et al., 2018, P. 2). The management literature has discussed different factors embedded in lock-ins that may drive the escalation of commitment. Staw (1976), for example, illuminates self-justification as a driver leading to an escalation of commitment. He describes how decision-makers may enlarge their commitment to previous decisions, despite the adverse outcomes, in order to avoid admitting past mistakes vis-à-vis themselves and vis-à-vis others . Staw (1981) further describes other factors driving the escalation of commitment, such as cultural and organizational norms: different players commit themselves to a certain course of action, which is not necessarily optimal, in order to avoid the violation of such norms . Another example may relate to Winch (2013), who argues that future benefits are an important motivation for strategic misrepresentation, associated with "optimism bias" and underestimation of future risks. This, in turn, facilitates the escalation of commitment because different players want to avoid missing out on these prospect benefits.

The underlying mechanisms behind these various factors, which drive the escalation of commitment, can be grouped under the overarching concept we describe as "regret cost." In the context of megaprojects, regret cost is defined as the "price" or efforts that must be invested to alter the course of a megaproject's action or to execute policy change during its planning and execution processes (Leib and Buckle, 2012). Corresponding with the examples presented above, regret cost may relate to admitting past mistakes, violating social norms, or missing out on prospective benefits. Unlike the common notion of sunk cost, which addresses past costs that have already been incurred and cannot be recovered, the notion of regret cost addresses future costs required to execute a change (Salonen, 2021; Wolsink, 2020).

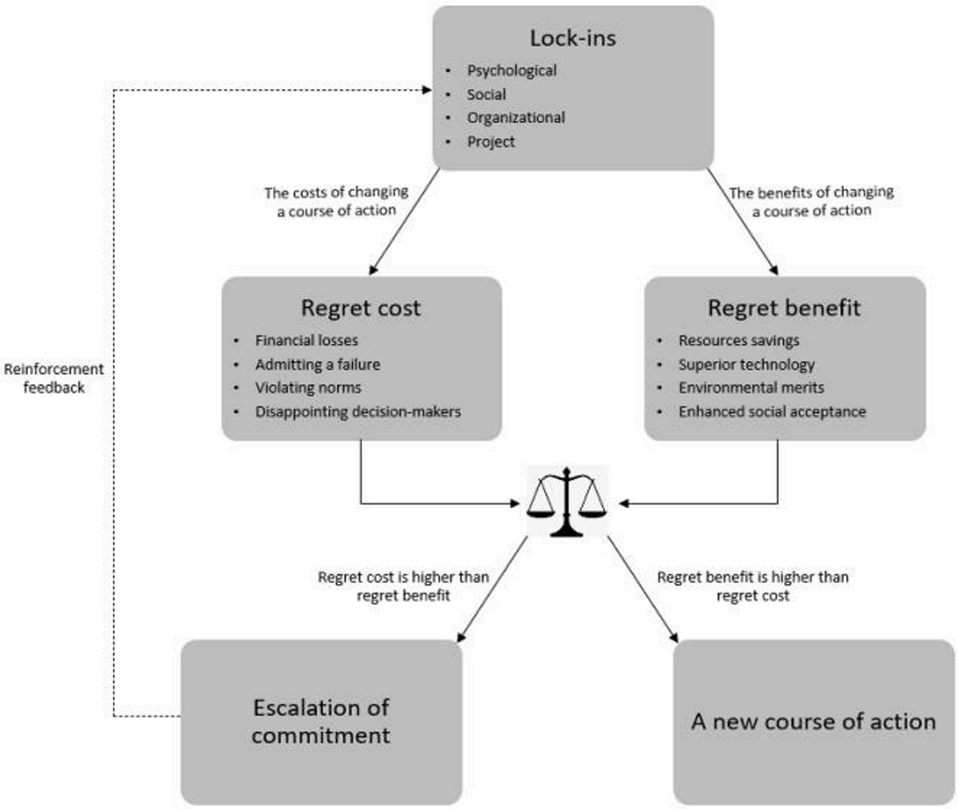

Fig. 1. The role of regret cost and regret benefit in the escalation of commitment.

Hence, regret cost is the outcome of lock-ins: the main strength of lock-ins and the inability to break out of them stems from the high regret costs they generate, which may make the "price" of changing previous decisions too high (Cantarelli and Flyvbjerg, 2013; Hetemi et al., 2017; Iyer, 2015). The concept of regret cost is accompanied by another concept, which we refer to as "regret benefit," i.e., the potential benefits associated with changing megaprojects' course of action (Staw, 1976; Winch, 2013), such as resources savings, superior technology, environmental merits, or enhanced social acceptance. Although players do not always rationally analyze the balance between regret cost and regret benefit in real-time (Staw, 1981), the escalation of commitment tends to occur when the regret cost is perceived to be higher than the potential regret benefit (Brockner, 1992). Arguably, therefore, lock-ins shape the escalation of commitment to megaprojects by increasing regulators' regret cost, which in return further strengthens the lock-ins (Cantarelli et al., 2010; Leijten, 2013; Priemus, 2008).

The financial aspect of regret cost has received much attention in the context of megaprojects, because it can be easily quantified. This aspect refers to the tangible amount of money required to change previous decisions concerning megaprojects due to reasons such as contract breaches, damages compensation, or planning of new projects (Bohringer and Rutherford, 2015; Leib and Buckle, 2012). Indeed, the evaluation of a megaproject's performance is frequently biased in favor of measurable factors; indeed, time, scope, and budget, the iron triangle of projects (Söderlund et al., 2012) , are the main guiding principles in conventional construction projects (Jones et al., 2016) . However, regret cost may also refer to other aspects, which are often harder to quantify. These may include psychological aspects, such as admitting a failure (Brockner, 1992); social aspects, such as failing to meet accepted norms (Geiger et al., 1998); and organizational aspects, such as disappointing decision-makers (Drummond, 2014) . With the same line of thinking, the literature (van Wijk and Fischhendler, 2017) has illuminated how the performance of a megaproject performance may also be evaluated in aspects that are intangible and thus harder to quantify, such as their compliance with social norms.

Fig. 1 below schematically illustrates how different groups of lock-ins may lead to the escalation of commitment to megaprojects through the mechanism of regret cost. As can be seen, four groups of lock-ins—namely, psychological, social, organizational, and project lock-ins—increase the regret cost. While a rationale analysis is not always conducted in real-time, the balance between regret cost (e.g., financial losses, admitting a failure, violation of norms, or disappointing decision-makers) and regret benefit (e.g., resources savings, superior technology, environmental merits, or enhanced social acceptance) may shape the fate of megaprojects. In this case, a new course of action may be taken when the regret cost is perceived to be lower than the regret benefit. Finally, as can also be seen in Fig. 1 below, as part of a feedback loop, the escalation of commitment further strengthens the lock-ins, and so forth.

4. Methodology

This study aims to explore the role of lock-ins in the escalation of commitment to RE megaprojects through the framework of regret cost. In order to address this issue, we used a qualitative case study approach (Yin, 2003) to examine the planning and construction period of the Ashalim thermal solar power station (2007–2018). The aim of this approach is to provide an understanding of the constructed social reality during the planning and construction of infrastructures (Yanow and Schwartz-Shea, 2015). The selection of a single case study approach provides the opportunity to collect in-depth data on the course of events around the establishment of a RE megaproject while reflecting upon its context and situatedness (Yin, 2003). We focus specifically on Ashalim as this represents an excellent example of an irreversible megaproject and is Israel's first and largest "flagship" RE megaproject. In particular, we examine the 150 MW thermal solar power station, which was constructed on Plot A of Ashalim and uses parabolic trough technology. This power station was the first of three-power stations constructed in Ashalim, which also included another 150 MW thermal solar power station based on power tower technology on Plot B, and a much smaller PV power station (30 MW) on Plot C. Furthermore, we had access to a wide range of internal documents concerning this megaproject, most notably in the form of the protocols of internal meetings.

To collect data on the Ashalim case, we used six clusters of sources (see Table 1): 1) formal government decisions concerning the megaproject; 2) protocols of the interministerial committee responsible for the establishment of the megaproject, and official documents regarding the tender; 3) regulations and data published by the Ministry of Energy and the Electricity Authority; 4) position papers published by various research institutes; 5) online newspaper articles about the megaproject; and 6) several field visits to the site. As can be seen in Table 1, some of these sources (no. 2, 4, and 6) were not published and were only made available after formal requests.

Table 1
Types of data used in the case study.

No.	Source	Data type	Public information
1	Prime Minister's Office	Official government decisions	Yes
2	Ministry of Finance	Internal meeting protocols; official governmental agreements; official tender's documents	No
3	Ministry of Energy and the Electricity Authority	Ministerial decisions and regulations; data about the Israeli electricity sector	Yes
4	Third-party organizations	Position papers about the Ashalim thermal solar power station and the Israeli electricity sector	Partial
5	Newspapers	Informative online articles about the Ashalim thermal solar power station	Yes
6	Field visits	Visual impressions of the operation of Ashalim	Partial

The data was analyzed via interpretive sense making – a practice of "dwelling" in the collected data (Welch et al., 2011). Such analysis, according to which data is understood within the context of the case, strengthens claims regarding actors' interpretations (Yanow and Schwartz-Shea, 2015). The analysis comprised five steps. First, the researchers familiarized themselves with specialized terms used in the case study. Second, we identified the chronological events in the establishment process of the RE megaproject through temporal bracketing (Langley, 1999). This allowed us to determine path-dependent events influenced by the various lock-ins. Third, these lock-ins were classified in accordance with Ross and Staw's (1993) four groups of determinants (project, psychological, social, and organizational). Fourth, based on this classification, we connected the lock-ins to the regret cost of various regulators, thus better understanding the escalation of their commitment to the RE megaproject over time. Finally, we analyzed three different, what we describe as "exit doors", i.e., opportunities to cancel or change RE megaprojects, during their execution stage, which in our case were avoided due to various lock-ins. We explain why these exit doors were not used through the prism of the various lock-ins and how they contributed to the Israeli authorities' escalation of commitment.

5. Case study

Based on the methodology described above, this section outlines the core of our case study: the planning and construction process of the Ashalim thermal solar megaproject. The case study is divided into three sub-sections, each describing an exit door not taken.

5.1. Meeting RE targets through the Ashalim megaproject

In 2007 the Intergovernmental Panel on Climate Change (IPCC, 2007) published a special report addressing policymakers. One of its main suggestions for mitigating climate change referred to the use of RE technologies. Influenced by *social determinants* related to the expected global norms, the then Israeli Prime Minister Ehud Olmert addressed this report in an official government meeting:

We want to be like the developed countries and deal with greenhouse gasses emissions as part of our own national program. The State of Israel, with 300 days of sunshine a year, can lead the global effort to produce alternative energy such as solar energy. (Sofer, 2007)

Yet, at this stage, the total installed capacity of solar power stations in Israel was negligible and included only several experimental facilities (Grossman and Libas, 2014).

According to the "green" path outlined by Olmert – and what Ross and Staw (1993) defined as *organizational determinants* – the Ministry of Finance's Budgets Department published a list of recommendations concerning the local energy market as part of the preparation for the 2008 state budget (Bar-Eli, 2007). Among the different recommendations, which mainly addressed conservative means of energy production, the ministry advised the government to promote several large-scale solar power stations in order to increase the country's installed capacity of RE and address global efforts to mitigate climate change (Eitan, 2021). The ministry advised locating these power stations in Israel's southern periphery, a desert region with vast empty land plots and suitable climatic conditions for solar power stations (Israel Electricity Authority, 2020). More specifically, the ministry pointed out appropriate land plots near a small town in southern Israel called Ashalim, an area previously identified by the state's Planning Administration as suitable for the establishment of large-scale solar power stations (Eitan et al., 2022).

In August 2007, the government decided to accept these recommendations and committed to the establishment of large-scale solar power stations. This was done in order to increase the national RE use, in keeping with other developed countries (Eitan and Fischhendler, 2022), and can be explained by *social determinants* related to international norms. The government published two official decisions (No. 2178 and No. 2390) ordering the establishment of two large-scale solar stations with a total installed capacity of 200–250 MW near the town of Ashalim. It appointed a committee comprised of the Ministry of Energy, the Ministry of Finance, and the Electricity Authority to examine the most efficient way to implement the decision and submit their recommendations (Israeli Government, 2007a, 2007b; Ronen, 2010). The government stated that "the committee… will form the economic basis for the feasibility of the project, including and bearing in mind, among other things, *cheap electricity rates*, in accordance with the policies established by the Electricity Authority" (Israeli Government, 2007b).

Two main families of technologies were considered by the relevant ministries: solar PV technology and thermal solar technology. While the former is based on solar panels which absorb and convert sunlight into electricity, the latter is based on two sub-technologies that convert heat energy into electricity: parabolic trough and thermal solar tower (Sukhatme and Nayak, 2017). Solar PV and thermal solar technologies were highly competitive at the time, and both were being used in a variety of projects across the globe. While solar PV required low initial capital and allowed flexibility in the power station's installed capacity, thermal solar could be combined with gas power stations while enabling the storing of energy (Bosetti et al., 2012; Peters et al., 2011).

Eventually, the ministries decided to recommend thermal solar technology, referring to its energy storage capabilities, which could save significant state expenses by enabling the provision of electricity even during the night (Eitan and Fischhendler, 2021; Ronen, 2010). With regard to the preferred establishment mechanism, the ministries recommended promoting a public–private partnership tender whose winner would be the bidder that agrees to accept the lowest payment from the state for every produced kWh of electricity. The main idea behind this was that the public sector would manage the tender, while its participators would be local and international private sector players (Ronen, 2010).

Based on these recommendations, another government decision (No. 3338) was published in March 2008, ordering the construction of two large-scale thermal solar stations (85–150 MW each) through a tender mechanism; alongside a much smaller PV solar station (10–30 MW), which would be constructed later. According to this decision, the tender would be managed by a special interministerial committee comprising the Ministry of Finance (led by the accountant general), the Ministry of Energy, and the

Electricity Authority (Israeli Government, 2008). These three governmental stakeholders were considered the most prominent regulators in the Israeli electricity sector, and their main task is regulating the relevant market, as well as initiating and promoting relevant projects for the benefit of the general public (Ministry of Energy 2022).

In April 2008, the tender's pre-qualification (PQ) documents were published by the interministerial committee, affirming the government's commitment to thermal solar technology. The main requirements for passing the PQ stage concerned financial capabilities and past experience in the establishment of solar power stations. No substantial obligations were yet required from the bidders in the tender, which resulted in seven bidders passing the initial stage in September 2008 (Maytal, 2008).

In January 2009, the government's commitment to promoting RE escalated, in particular regarding the Ashalim RE megaproject. The government published an official decision, influenced by Ross and Staw's (1993) *social determinants* relating to international norms about electricity production using RE. It announced a new target of 10% electricity production based on RE by 2020 (Decision 4450), emphasizing the attempt to conform with the actions of other developed countries. The government also referred to the Ashalim RE megaproject as the "flagship" of the state's efforts to promote RE (Israeli Government, 2009).

This official statement urged the interministerial committee to progress with the Ashalim RE megaproject, according to what can, once again, be described as *organizational determinants* stemming from political support. Indeed, in March 2009, the official tender's documents were published, specifying the winner's complete requirements including the specific technology to be used in Plot A: parabolic trough. According to these documents, the state would sign a BOT (build-operate-transfer) agreement with the winner of the tender for the financing, construction, and operation of the thermal power station for a period of 28 years: three years for its construction and 25 years for its commercial operation. During the commercial operation phase, the winner would be paid a fixed (index-linked) amount of money for every kWh of electricity produced according to its winning bid. At the end of this period, the power station would become state-owned (Ministry of Finance, 2009).

Even though the full tender's documents were published in March 2009, the submission date for the bids was repeatedly delayed, since the interministerial committee made repeated adjustments to the tender's technical and legal requirements. These adjustments stemmed from the fact that this was the first ever RE megaproject in Israel and, specifically, a megaproject being promoted by the state. Hence, due to the state's limited experience in the field, the interministerial committee was struggling with pre-institutionalizing all the technical and legal terms of the tender addressing the long 28-year contract period (Ministry of Finance, 2016).

Eventually, the submission date of the final bids was set to February 2011. However, due to the long time that had passed since the PQ stage and the multiple adjustments along the way, most of the candidates who passed that stage had withdrawn their bids and only a single bid was submitted by Negev Energy, a company jointly owned by the Israeli Shikun VeBinui (50%) and the German Siemens AG (50%). Some speculations regarding the massive bids withdrawn addressed uncertainty about the project due to its long (28-year) duration as well as the repeated adjustments of the requirements which raised doubts concerning the state's ability to manage such a large-scale tender (Gutman, 2012a).

Ministry of Finance representatives in the interministerial committee pointed out that the single bid portended the cancelation of the entire project. They viewed it as raising a red flag since it reflected the private sector's lack of interest and suggested that the committee reconsider its actions concerning the tender (Ministry of Finance, 2011). The committee therefore decided to convene to discuss future steps due to the withdrawal of most bids. During this meeting, it was agreed that the tender procedure would be suboptimal with only one bidder and that the withdrawal of the other bids constituted a warning sign concerning the tender in its current form. (Gutman, 2019b; Ministry of Finance, 2011).

At this stage, the State of Israel had no significant legal or financial obligations toward the single bidder and could therefore cancel the project with limited compensation. Thus, if the committee had regretted the RE megaproject at this point, it could have addressed and better understood the reasons for the private sector's lack of interest. However, due to the *organizational determinants*, shaped by the government's support for achieving its RE targets via the Ashalim megaproject, the committee, instead, escalated its commitment to the megaproject. In its decision to continue with the project and evaluate the single bid, the committee stated that "this flagship solar power station will assist Israel to meet its RE targets while fully expressing its commitment to addressing global concerns about climate change" (Ministry of Finance, 2011). Hence, path-dependent events increased the committee's regret cost at this stage – a cost that was related to non-compliance with global norms of promoting RE and, more importantly from the committee's perspective, the failure to follow official government decisions, backed by significant political support. This resulted in the committee's decision to continue with the Ashalim RE megaproject while preventing its cancelation or transformation despite significant warning signs (Hovel, 2011; Ministry of Finance, 2011).

5.2. Protecting the state's reputation through the Ashalim megaproject

After in-depth consultations, the interministerial committee decided to continue with the tender for the financing, construction, and operation of the Ashalim thermal power station despite the submission of only a single bid. Indeed, in January 2012, the committee reconvened in order to evaluate the bid submitted by Negev Energy (Ministry of Finance, 2012a). The bid reflected a price of 1.02 NIS (€0.26) to be paid by the state for every kWh produced. Ministry of Finance representatives stated that this bid was much higher than the estimation before the tender of around 0.8 NIS (€0.2) for every kWh produced due, they claimed, to the lack of competition and the growing price gap between thermal solar technology and solar PV technology over the years. The price of the rival PV technology had, in fact, seen a sharp global decline with the price for similar size power stations being around 0.55–0.6 NIS (€0.14–15) for every kWh produced, demonstrating a price gap of more than 40% between the two technologies (Ministry of Finance, 2012a).

Due to this price gap, there were calls within the committee to cancel the current tender and promote a new tender for a large-scale

PV power station. However, all agreed that cancelling the project could have negative implications (Ministry of Finance, 2012a) and might highlight the committee's failure to promote it, thus demonstrating the influence of *psychological determinants*. The regret cost at this stage was therefore related to publicly admitting the failure of the megaproject – an admission that may, in turn, be seen to reflect the state's inability to manage such large-scale tenders and a possible withdrawal of its commitment to promote RE and thus damage future private sector involvement in the field (Ministry of Finance, 2012a).

Hence, it was decided to conduct an independent cost analysis to determine a reasonable price for the megaproject. Based on the new cost analysis, and in an attempt to avoid cancelling the tender, the committee advised Negev Energy to resubmit its bid in June 2012 at a new price of 0.86 NIS[1] (€0.215) for every kWh produced. This price was still considerably higher than similar-sized PV power stations but still considered a very low price for similar thermal solar power stations from a global perspective (Ministry of Finance, 2012a, 2016).

Another warning sign concerning the competitiveness of thermal solar technology was evident in late 2012. Negev Energy requested amendments to its ownership structure, enabling the Spanish company Abengoa to replace Siemens. This stemmed from a decision by Siemens to disengage from thermal solar power stations due to their realization that solar PV was going to be the more dominant technology in the ensuing years, specifically because of its low prices (Gutman, 2012b, 2012c).

The interministerial committee perceived this request for ownership change as an opportunity to reconsider the necessity of the entire project in light of the low competitiveness of thermal solar technology and its high price relative to solar PV. A special meeting was held to discuss the request: rejection would lead to cancelation of the project in its current form, while approval would enable the project to continue as planned (Ministry of Finance, 2012b). During the meeting, committee members addressed once again the considerable price gap between the chosen thermal solar technology and the alternative PV technology. Electricity Authority representatives mentioned that continuing with the current tender would increase the price of electricity and thus impose a significant financial burden on Israeli citizens of around 2.1 billion NIS (€525 million) in comparison to a PV power station of a similar size. The Siemens decision to stop its engagement with thermal solar technology was regarded as a strong indication that this technology should be abandoned. Ministry of Energy representatives saw the request for ownership change as a good opportunity to cancel the tender if the committee so desired without the need to address other aspects of the tender procedure (Ministry of Finance, 2012b).

Thus, by regretting the RE megaproject at this stage, the committee could have avoided the use of such expensive technology. However, eventually, the committee decided to approve the request for ownership change and continue with the tender under the condition that Negev Energy would agree to the new counterproposal of 0.86 NIS (€0.215) per kWh. In its decision to continue with the project, the committee addressed several issues (Ministry of Finance, 2012b), most notably, the fact that cancelling the tender at this stage could harm the state's reputation in two main ways, both of which constitute the increased regret cost associated with cancelling the megaproject at this stage and are influenced by the *social determinants* relating to expected norms. First, cancelation might signal to the local energy industry that the state is struggling with its promotion of RE. Second, it might signal to international companies that official proposals offered by the State of Israel (such as the counterproposal) cannot be trusted. This may, in turn, affect the willingness of local players to take risks and engage with future RE projects due to an understanding that even the state, which can, unlike private players, adjust the regulation in its favor, is unable to reach the finish line. In addition, the lack of trust in Israeli authorities may deter foreign players from participating in future infrastructure tenders, specifically in the RE field.

Indeed, approval of the ownership change allowed the project to continue, and, in June 2013, after Negev Energy updated its price offer in accordance with the committee's counterproposal, it was announced winner of the tender (Globes, 2013).

5.3. Legal obligations toward the Ashalim megaproject

In September 2013, the State of Israel signed a BOT agreement with Negev Energy. According to the agreement, Negev Energy would be responsible for the financing, construction, and operation of the Ashalim thermal power station for a total period of 28 years. At the end of this period, the power station would become state-owned and continuation of its operation would be subject to its physical and technical condition. In return, Negev Energy would receive 0.86 NIS (€0.215) for every kWh delivered to the national electricity grid, which would be financed by the electricity tariff paid by all Israeli consumers. Thus, by signing the agreement, the state legally committed itself to the construction of the megaproject (Slosberg, 2015).

Negev Energy completed the financial closure procedure of the project in July 2015. Four billion NIS (€1 billion) was raised from the Overseas Private Investment Corporation, the European Investment Bank, and the two largest Israeli banks, Hapoalim and Leumi. The interministerial committee approved the project's financial closure, thus further binding itself to the project, due to the financial involvement of both local and international banks, which relied at this stage on the state's commitment to promoting the project. This escalation of commitment was therefore influenced by *project determinants* relating to both the financial and legal obligations toward various stakeholders. On approval of the financial closure, the committee allowed Negev Energy to begin actual construction (Sahar, 2015).

Yet, less than a year later, Negev Energy submitted another request for ownership change. The Spanish company Abangua had encountered financial distress and found itself on the verge of bankruptcy in several countries, so Negev Energy requested additional amendments enabling the Spanish company TSK Group (10%) and the Israeli Noy Fund (40%) to join Shikun VeBinui (50%) instead of Abangua. The interministerial committee reconvened to discuss the request for ownership change, perceiving it once again as a

[1] 0.79 NIS index-linked.

possible exit door in light, in particular, of the use of thermal solar technology instead of the cheaper and more globally common PV technology. Doubts were also raised concerning the capability of the private developer to execute such a complex megaproject (Bar-Eli, 2016; Gutman, 2016).

According to estimations made by the Ministry of Finance, replacing the thermal solar power station with a PV power station at this stage could save the state 245 million NIS (€61 million) per year and a total of 3.1 billion NIS (€775 million) capitalized over the entire lifespan of the project. According to the Electricity Authority's estimations, the savings could reach a total of 4.25 billion NIS (€1.06 billion), which could reduce the consumer price of electricity by approximately 0.07–0.1 NIS per kWh (€0.018–0.025). During the meeting, it was also emphasized that when the tender was launched in 2008, the price gap between the two technologies was far smaller (Ministry of Finance, 2016).

If the committee had regretted the RE megaproject at this stage, it could have minimized concerns about the developer's capabilities while removing the financial burden from the taxpayers. However, the committee decided, once again, to approve the ownership change and continue with the project as planned (Ministry of Finance, 2016). This decision was made for several reasons, the most prominent relating to the state's legal obligation toward the winner of the tender, which significantly raised its regret cost. After the signing of the BOT agreement and the financial closure with Negev Energy, the state had no legal way of cancelling the project and would need, according to the committee's estimations, to pay Negev Energy compensation of around 2.5 billion NIS (€625 million). This would reduce the financial advantages of cancelling the project, making such a decision unprofitable in accordance with *project determinants* relating to sunk costs. The committee considered other options rather than cancelling the entire project such as converting part of it to PV technology and compensating Negev Energy for the change. However, these options were also rejected, since the compensation needed for the private developer would have made such changes unprofitable (Ministry of Finance, 2016).

Approval of this second ownership change in March 2016 enabled the project's continuation and allowed Negev Energy to now focus on the actual construction of the power station. Thus, the legal and financial obligations toward the tender's winner increased the regret cost associated with cancelling the megaproject, resulting once again in its continuation. In fact, the power station reached its run-in and testing phase in July 2017 and began full commercial operation in July 2018, more than a decade after its initial planning (Gutman, 2019a). Israel has subsequently seen tremendous growth in the establishment of solar facilities; according to the International Energy Agency (IEA), as of 2020, Israel ranked second in the world and first among OECD countries in the share of electricity generation from solar energy. However, besides the Ashalim power stations, all of these facilities are based on solar PV due, primarily, to its cost-related advantages (IEA, 2020). Table 2 summarizes the main events along the timeline of our case study.

Table 2
Timeline of events and emerging exit doors.

No.	Time	Milestone	Lock-ins	Regret costs	Regret benefits
1	March 2008	Government's decision			
2	January 2009	RE targets are set			
3	March 2009	Tender documents are published			
4	February 2011	Single bid is submitted			Addressing the private sector's lack of interest
	Exit door 1				
5	January 2012	Decision to progress with the single bid	Organizational lock-ins	Failing to meet the government's climate goals	
6	March 2012	Independent cost analysis is conducted	Psychological lock-ins	Admitting failure of the project	
7	June 2012	Committee's counterproposal			
8	January 2013	Developer's request to change holdings			Avoiding the use of expensive technology
	Exit door 2				
9	March 2013	Approval of developer's new holdings	Social lock-ins	Harming the state's reputation	
10	June 2013	Developer updates its bid			
11	September 2013	BOT agreement is signed			
	July 2015	Approval of the project's financial closure			
12	September 2015	Developer's bankruptcy			Minimizing concerns about the developer's capabilities; removing the financial burden from taxpayers
	Exit door 3				
13	March 2016	Reapproval of developer's new holdings	Project lock-ins	Financial and legal uncertainty	
14	July 2018	Commercial operation begins			

6. Discussion

This study addressed the mechanism of path-dependent lock-ins in the process of establishing the giant thermal solar power station constructed near Ashalim, while illuminating the concept of regret cost. Our findings contribute to two streams of academic literature. The first contribution relates to the energy transition literature, specifically concerning RE megaprojects (Dai et al., 2016; Gutierrez et al., 2019; Nelson et al., 2013). Although the energy transition debate has mostly focused on decentralized RE infrastructure (Tan et al., 2013; Tazvinga et al., 2017; Yaqoot et al., 2016), RE megaprojects have grown notably in recent years, enabling the provision of substantial amounts of clean energy (Irena, 2020). Indeed, as Sovacool and Geels (2021) noted, it is essential that we understand the contribution of RE megaprojects to the energy transition process, and this study specifically focuses on how such megaprojects are shaped by the mechanism of path-dependent lock-ins.

Our findings thus demonstrate how various lock-ins can influence RE megaprojects in particular, contributing to their low flexibility, specifically during their execution stage, and preventing the adoption of superior technologies along the way. As shown in the study, such lock-ins constitute the underlying mechanism for increasing regulators' regret cost, thus escalating their commitment to RE megaprojects, and possibly resulting in their irreversibility. This possible inflexibility of RE megaprojects questions the role of RE megaprojects in the energy transition process (Burger et al., 2019; Sovacool and Cooper, 2013; Yaqoot et al., 2016), as it may contradict the growing need for new opportunities and degrees of freedom in energy markets, specifically in terms of technology improvement, increasing efficiency, and decreasing costs over time (Bayer et al., 2013; Chen and Lei, 2018; Elia et al., 2021; Saygin et al., 2015). Hence, in response to the call by Sovacool and Geels (2021) to deepen research regarding megaprojects, specifically in the RE field, our study has shown that while these megaprojects may be essential in promoting the transition to a low-carbon society, they entail inherent weaknesses given their tendency to be shaped by lock-ins. Despite these findings, megaprojects are still likely to thrive as part of the RE transition (Irena, 2020). Like many other countries, Israel recently set ambitious RE targets as part of the Paris (Tal, 2016) and Glasgow (Khenin, 2021) United Nations Climate Change Conferences. To meet these high targets, local regulators are encouraged to promote additional RE megaprojects (Ashkenazi, 2022), which could be subject to significant lock-ins, especially considering the significant political pressure in this respect.

The second contribution of this study concerns project management literature regarding lock-ins in megaprojects (Hetemi et al., 2021; van Marrewijk, 2017: (Drummond, 2014) ; Winch, 2013; Cantarelli and Flyvbjerg, 2013). Our case study has revealed how four groups of lock-ins—project, psychological, social, and organizational—have evolved to contribute to the escalation of commitment in different stages of the project by increasing the regulators' regret cost. In particular, the study has shed light on the influence of lock-ins *within* megaprojects (Cantarelli and Flyvbjerg, 2013), specifically focusing on their execution stage. In line with others (Brockner, 1992; Sleesman et al., 2018), we showed that the fate of the megaproject was not decided by individuals but by a series of lock-ins (project, psychological, social, and organizational) strongly associated with the regret cost they impose on regulators, escalating their commitment to megaprojects.

In our case, the various lock-ins did not replace one another, as Beyer (2010) has suggested, but rather reinforced each other as the megaproject progressed, thus increasing regulators' regret cost over time. For example, the organizational lock-ins, relating to political support, contributed to the enhanced efforts of the interministerial committee, thus reinforcing psychological lock-ins relating to the self-justification of such efforts. Herein lies the power of lock-ins: they reinforce each other over the lifespan of megaprojects and therefore contribute to a steady increase in the regret cost. This is what Drummond (2017) called the "escalating inevitability," namely, when project factors play out as one suboptimal decision, forcing a chain of suboptimal solutions.

The literature concerning megaprojects has discussed several strategies to prevent or ease lock-ins: for example, periodical review points throughout the megaproject's lifespan (Drummond, 2017; Merrow, 2011; Barshop, 2016), increasing the checks and balances (Cantarelli and Flyvbjerg, 2013). In line with this, Priemus and Wee (2017) suggested splitting the decision-making process into parts and distinguishing between "no regret" parts and others in which "no regret" decisions can be made earlier. Furthermore, other suggestions have been made to reduce the risk of lock-ins in megaprojects, such as more realistic front-end planning (Flyvbjerg, 2009), the setting of limits (Drummond, 2017), and, more radically, the total avoidance of promoting megaprojects (Attia, 2020; Beer, 2017; Vidaurre, 2017).

However, our case study has demonstrated that the effectiveness of such instruments is highly doubtful, thus indicating the problematic nature of governing megaprojects. Our findings demonstrated that various solutions—such as conducting rigorous front-end planning (identified here with the committee's pre-planning stage), or setting limits (identified here with the independent cost analysis)—did not result in recycling or stopping the megaproject, despite its apparent suboptimal outcomes. In particular, the regulators and their institutions in our case consciously continued with the alleged suboptimal path of the RE megaproject despite the emergence of what we refer to as exit doors (e.g., the request for a change in ownership, the failing tender procedure, and the developer's bankruptcy). Unlike the concept of gate reviews, which are conducted during the design stage (Flyvbjerg et al., 2003; Merrow, 2011; Barshop, 2016), the concept of exit doors that we introduced here should enable the parties involved to change megaprojects' course of action even during their execution stage.

Thus, this study demonstrated how, despite the emergence of exit doors that allow regulators and their institutions to reduce regret cost while enjoying regret benefits, in practice, it is not easy to use such doors because the regret benefits are often no match for the significant regret costs of megaprojects. This balance between regret cost and regret benefit is not necessarily a rational decision based on probabilities and precise analyses. As shown in our case, it is also affected by intangible costs, which are harder to quantify (van Wijk and Fischhendler, 2017), such as compliance with social or cultural norms. In our case, for example, the regulators' inability to switch the technology of the megaproject in order to save resources (i.e., regret benefit) resulted from the intangible cost to the state's reputation if it were to admit failure (i.e., regret cost).

7. Conclusion

Anecdotal evidence around the world has indicated that RE megaprojects often continue to be developed with limited changes despite the emergence of alternatives alongside their planning and construction processes (Burger et al., 2019; Sovacool and Cooper, 2013; Yaqoot et al., 2016). Our study addressed this issue by providing empirical evidence for the role of path-dependent lock-ins in the irreversibility of RE megaprojects, focusing on the notion of regret cost (Bohringer and Rutherford, 2015). In particular, the study shed light on the influence of lock-ins within megaprojects, specifically focusing on their execution stage. We did this by examining the establishment process of a giant thermal solar power station near Ashalim, a small community settlement in southern Israel. This study's findings have contributed to a better theoretical and practical understanding of the limitations of RE megaprojects in the global energy transition. We questioned their ability to meet the energy market's growing need for increased flexibility, which seems to be an important condition in the transition process (Eyre 2013).

Limitations of our study should nonetheless be addressed. First, our findings are based on a single case study whose characteristics may not be completely relevant to other countries or regions concerning, in particular, different RE policies. Second, we did not quantitatively examine the balance between regret costs and regret benefits but relied primarily on the revealed preference of the regulators themselves. Third, our study did not explore whether certain strategies to prevent lock-ins are more efficient than others according to the circumstances or specific types of lock-ins. Finally, our study did not investigate the possible influence of path-dependent lock-ins on decentralized RE as an alternative for RE megaprojects.

With these limitations in mind, we suggest that future studies conduct additional research about the irreversibility of RE megaprojects in different regions across the world in order to validate or refute our findings in different context. Moreover, future studies should try to quantify the balance between the regret costs and regret benefits of RE megaprojects, including those which are intangible, and thus provide a more accurate tool to evaluate the role of RE megaprojects in the energy transition process. Finally, new research should investigate the strengths of lock-in mechanisms and how they vary over time, as others have suggested (Köhler et al., 2019), examining more deeply the influence of different strategies on the prevention of lock-ins, specifically in the context of RE megaprojects.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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