

Research article

Cross-technology legitimacy feedback: The politics of policy-led innovation for complementarity in concentrating solar power

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ABSTRACT

Solar photovoltaic and wind power generation is expanding fast globally, fuelled by technological progress and rapid cost reductions. Other renewable power technologies fare much worse: deployment stagnates despite substantial technological progress. Here, we explore why these technologies fall off political agendas although they are improving, proposing that negative cross-technology feedback from more dynamic, faster deployed technologies reduce the legitimacy of laggard technologies. This generates political pressure to cancel or adapt support schemes, which in turn may push the laggard technology to change and become more complementary to the dynamic technologies. We illustrate our propositions with a case study of concentrating solar power (CSP) policy and deployment in three countries. We show how negative legitimacy feedback from the dynamic diffusion of photovoltaics and wind power in the 2010s led to both policy termination and technological adaptation towards complementarity, changing CSP from a generation to a storage and balancing technology.

1. Introduction

The transition towards a climate-neutral economy is well under way, as fully renewable energy systems appear technically realistic and increasingly economically attractive (Brown et al., 2018; IRENA 2021). Following ambitious deployment policies in several countries, renewable power technologies have matured and solar photovoltaics (PV) and wind power are today, in 2024, among the cheapest sources of electricity in most places and expand also in unsubsidised markets (IRENA 2022). Consequently, PV and wind power dominate decarbonization visions, deployment, and investment (Haegel et al., 2019; Thonig et al., 2021).

The increasing reliance on intermittent wind power and PV raise the need for additional flexibility options – either dispatchable supply, storage, or greatly expanded power grids – to keep the power system stable (Tröndle et al., 2020). Whereas such options exist (Breyer et al., 2022) and are foreseen in decarbonisation scenarios (IEA 2021b), especially flexible generation technologies are deployed only slowly (REN21, 2023). In 2022, global clean power investment excluding PV and wind even decreased (Wiatros-Motyka, 2023). This raises questions of why some zero-carbon technologies are deployed at scale whereas others are hardly deployed at all.

Abbreviations: BW, bid window; CCS, carbon capture and storage; CSP, concentrating solar power; FYP, five-year plan; IPP, independent power producer; MW, megawatt; PPA, power purchase agreement; REIPPP, Renewable Energy Independent Power Producer Procurement Program; SM, solar multiple.

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One possibility to understand the (non-)deployment of new technologies is to investigate the evolution of the policies that support them (Schmid et al., 2020). There is much literature on policy-technology feedback, describing how maturing technologies gain momentum and start creating their own politics (Rosenbloom et al. 2019), such as is the case for PV (Strauch, 2020). As a technology is deployed, its costs decrease and performance increases, and it is increasingly seen as appropriate, promising, or *good* in the broadest sense: its technological *legitimacy* increases (Suchman, 1995). This justifies continued deployment support (Pierson, 1993; Sewerin et al., 2020), which triggers continued technological progress.

However, this does not explain why some promising technologies fall off political agendas although their technological progress is fast, and although there seems to be need for them in the future, e.g. expressed in decarbonisation scenarios. Here, we seek to explain such techno-political trajectories.

Concentrating solar power (CSP) is one such case: as the technology improved (Mehos et al., 2020) and costs decreased by some 70 % in 2010–2020 (IRENA, 2022), one would expect accelerating deployment and a strengthened coalition. The opposite is however the case: although some see a future need for CSP (Kennedy et al., 2022; Resch et al., 2022), the technology was supported only in a few countries and global deployment is stagnating (Lilliestam et al., 2021).

Because the existing literature focuses on single-technology feedback effects, it is unclear *why* CSP (or, e.g., carbon capture and storage (CCS) or nuclear power) has failed to enter a virtuous technology-policy feedback cycle similar to that of PV (Nemet 2019), but only *that* it has failed to do so. We propose that this happened due to competition from other technologies: CSP fell off the agenda, because PV and wind power developed faster and gained in relative legitimacy, thereby pushing CSP out of policy support and hence further deployment and development. Our theoretical contribution is thus to suggest, and the to empirically illustrate, a mechanism of how cross-technology legitimacy feedback – specifically the gain in legitimacy of a successful technology – decreases (relative or absolute) technological legitimacy of other technologies, thereby constituting a negative feedback contributing to ratcheting down the ambition of support policies for less successful technologies. To substantiate and illustrate this, we empirically explore legitimacy feedback effects between CSP and other power technologies in the three countries (Morocco, South Africa, and China) that have had active CSP deployment policies in the last decade. We show that the hypothesis holds: the observed relative loss in CSP legitimacy compared to PV and wind power has strongly and directly contributed to shrinking CSP support and deployment ambition, despite continuous technological improvement.

In the following section (2) we proceed to review the policy-technology feedback literature and develop a multi-technology legitimacy framework, suggesting that cross-technology feedback is a missing link to understand policy developments for specific technologies. We then introduce our case studies of CSP deployment in South Africa, Morocco, and China (Section 3) and illustrate our theoretical proposition by exploring the technology and policy dynamics of CSP, showing how cross-technology feedback affected the political case for and the technological trajectory of CSP (Section 4). In Section 5 we discuss these results and draw conclusions in Section 6.

2. Technology feedback and the role of legitimacy

2.1. The virtuous cycle of policy-led technology development

2.1.1. Technological learning

Technological learning is the process of how technologies improve. New and immature technologies tend to be more expensive and less well-performing than incumbent technologies. Apart from laboratory research, real-world learning by doing, using, and interacting is particularly important to enable innovations to succeed (Nemet et al., 2018; Alhusen et al., 2021). Over time technologies become more efficient, reliable and cheaper, as learning in manufacturing, operation and financing improve the entire value chain (Arrow 1962; Egli 2020). Deployment and learning thus interact closely: deployment leads to learning, which may increase deployment because the new technology is improving and is expected to continue improving (Grubb et al., 2021). Additional demand in new applications or niches increases the potential market and may accelerate learning, whereas losing an application can slow or stop deployment and learning (Malhotra et al., 2021). Through such positive policy-technology feedback, new technologies may replace and help phase out unsustainable technologies, thus driving sustainability transition (Geels et al., 2017; Köhler et al., 2019).

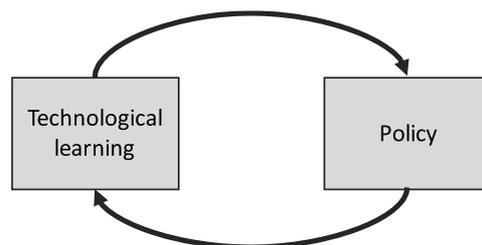


Fig. 1. The simple policy-technology feedback cycle for policy-led technology innovation: initial policy support leads to deployment and technology outcomes, which feeds back into evaluating political support for = supportive policies. This can be both positive or negative feedback, depending on the technology outcomes. Adapted from Schmidt and Sewerin (2017).

2.1.2. Public policies can drive technological learning

Desired sustainable technologies are initially typically neither good nor cheap enough to survive in the market and overcome the lock-in of unsustainable technologies (Unruh, 2002; Simoens et al., 2022). Thus, policy interventions can create demand and help finance deployment (Haddad et al., 2022). This demand-pull may trigger technological learning and initiate a policy-led transition (Bergek et al., 2015; Kanger et al., 2020). Ultimately, such policy approaches aim to improve the technology sufficiently to achieve self-sustained diffusion, so that subsidies can be reduced or stopped (Melliger and Lilliestam, 2021; Sharpe and Lenton, 2021).

Policy and technology influence each other over time: improving (or decreasing) technology performance affects chances for continued or strengthened policy support, which affects the subsequent technology trajectory. This implies that *current* cost of a desired maturing technology is a function of, among other things, prior policy interventions and the triggered technological learning (Lilliestam et al., 2017; Rosenbloom et al., 2019). More support may enable faster technology learning, eventually driving a virtuous cycle with positive feedback of deployment leading to learning, leading to ratcheting up of policy support and ambition, driving more deployment (Fig. 1) (Schmidt and Sewerin, 2017; Sewerin et al., 2023). Vice versa, slow technological progress may create a reason to cut resources for that specific technology (negative technology feedback). This then slows down deployment and thus learning so that the technology stagnates, offering further reason to cut resources and ratchet down ambition, and the technology may never reach self-sustained development without policy support.

2.2. Positive feedback effects: increasing technological legitimacy

In transition studies, *technological legitimacy* describes the alignment of a technology with its context (Markard et al., 2016): the subjective understanding of a technology and the problems it may help solve in the current socio-technical system with its institutions, interest groups and political culture (Lockwood, 2022). In the policy sciences, this subjective understanding is understood as an interpretation of system parameters (such as technology properties) by actors holding their respective policy beliefs, which is updated over time, as a function of dominant constructions and interpretations of observations of how previous policies and strategies have played out (Sabatier, 1988; Thompson et al., 1990). Technological legitimacy thus helps describe the subjective evaluation of whether a technology is worth supporting at a point in time. If policymakers decide to invest resources to support a, in their evaluation, legitimate technology, successful projects may trigger technological learning which may subsequently feed back into increasing policy ambition in further positive iterations of this *legitimacy-policy-technology cycle* (Fig. 2).

As a technology improves, its costs decrease and/or its performance increases, alleviating constraints that were previously binding and limiting policy ambition. Combined with growing coalitions supporting such technologies, the likelihood that this technology will enjoy continued or increased political support is high (Meckling et al., 2015; Pahle et al., 2018). However, in this article we note that this mechanism does not explain why some well-developing technologies still stagnate.

Here, we propose that not only the *absolute* increase in technological performance and coalition development determine the continued support, but also the *relative* development compared to other technologies in the same system. In Fig. 2, this means that not only the development of the technology itself but the alignment with its context development matters too (Markard et al., 2016). The evolution of adjacent technologies is a key aspect of that context alignment.

Conceptually, technology legitimacy builds on the notion of legitimacy as a “generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions” (Suchman, 1995). Markard et al. (2016) use it to describe how a technological innovation system (TIS) of industry and other stakeholders aligns with its institutional context (Bergek et al., 2015), including policy support for the technology. Departing from the TIS focus, here we use the term to describe the continuously evolving interpretation of a technology by policymakers¹ reflected in policy output. This refers to technology-specific ideational feedback (Béland and Schlager, 2019) – how the *idea* of a technology within each national *system* changes over time. This can happen for example as technologies develop at different paces, as new problems (or solutions) arise, or because political majorities shift and the dominant interpretation changes with them (see Sections 2.3 and 2.4).

In line with Suchman (1995) we distinguish three interconnected pillars of legitimacy that all reflect how policymakers may evaluate the merits of spending resources on a technology. First, *moral legitimacy* describes that something is “the right thing” under the circumstances; this is the interpretation of a specific technology as fitting for the current agenda. This is especially relevant for policy support to counter lock-in of polluting technologies (Trencher et al., 2020) as costs of this are immediate but the benefits materialise only later, so policymakers must justify how spending now contributes to a *better future*. Here, expected technological performance and future needs inform the case for a specific technology. Beyond technological learning, deployment also helps building the TIS and industries around it. Thus, policymakers may also seek co-benefits including new jobs, export revenues, or impulse for regions in structural change. Supporting policy decisions are thus more likely if they fit multiple political agendas, including (green) economic growth and environmental policy (Hedeler et al., 2023).

Second, *pragmatic legitimacy* refers to something being in the self-interest of decisionmakers, meeting their goals and helping them stay in power. Here, this refers to whether (and to which extent) a technology, and thus spending resources on this technology, aligns with interests of important or powerful stakeholders. As a TIS grows, it creates its own coalition of supporters (Schmid et al., 2020,

¹ Different stakeholders of the TIS and the wider socio-technical system may hold different views on a technology’s legitimacy. Here we are only interested in the dominant interpretation of policymakers in the frame of their evaluation of which technologies are worth spending resources on, as we investigate the question why some technologies fall off the political agenda, thus we do not fully adopt all TIS functions or set out to capture the full diversity of these diverging technology legitimacy interpretations.

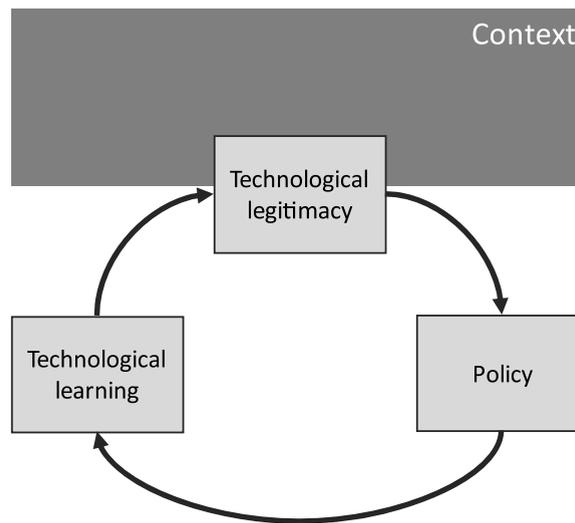


Fig. 2. The virtuous legitimacy-policy-technology feedback cycle: high technology legitimacy triggers initial policy support that leads to technological progress, which increases the legitimacy and later enables additional policy support. In subsequent iterations of the cycle, previous outcomes inform the interpretation of a new alignment with the evolved context (which also holds the development of adjacent technologies) to inform policy change.

Eicke and Weko, 2022) which increasingly influences politics (Schmidt and Sewerin, 2017). This can be the mechanism for a positive feedback cycle – deployment triggers coalitions that request support, which triggers deployment (Meckling et al., 2015, Pahlé et al., 2018). Thus, existing champions or business interests for a technology may increase the likelihood for continued political support of favoured innovations (Bergek et al., 2008).

Third, *cognitive legitimacy* describes the *interpretation of what a technology does or will do*. For early technology support, this holds the policymakers' hopes and expectations attached to a specific technology, such as wind power delivering sustainable and very cheap electricity. This view of a technology's intended task or market niche informs both pragmatic and moral legitimacy and may change over time (Dehler-Holland et al., 2021), either as the technology evolves to serve different niches or purposes or as norms or problem perceptions change. For example, increasingly PV is now understood as an inevitable source of cheap bulk power in most places, but the role of or need for carbon capture and storage in both energy and industry remains contested and unclear.

All three dimensions contribute to legitimise policies. Ideally, *pragmatic* short-term and *moral* long-term benefits align, and the technological outcomes are consistent with policymakers' expectations (*cognitive legitimacy*). Then, high initial technological legitimacy may trigger self-reinforcing positive *legitimacy-policy-technology feedback* (Fig. 2).

2.3. Negative feedback effects: decreasing legitimacy

A virtuous cycle does not always arise, or an existing one may break down, due to problems with technology outcomes, political changes, or evolving context-alignment (Fig. 2). Whereas the politics of technology support have been well studied (Breetz et al., 2018; Kern and Rogge, 2018), the effects of changing contexts on technological legitimacy and especially on policy support has been less often investigated. In particular, cross-technology effects – how successful policies for one technology affect the legitimacy of an adjacent technology – have not been thoroughly investigated.

2.3.1. Technology outcomes

Sometimes, technology outcomes diverge from expectations (Garud et al., 2014). Technical innovation failures (Baxter et al., 2023), delays or cost overruns (Ansar et al., 2014) contribute to a loss of pragmatic legitimacy and undermine the case to spend on additional projects. Thus failing to reach the *intended* technological goals may lead to abandoning support for a specific technology route (Turnheim and Sovacoo 2020). Indeed, if a niche technology is encountering problems, policymakers may be inclined to try another technology that, based on available knowledge and projections, better satisfies their preferences and problem definitions (Verbong et al., 2008). Thus, just as technology choices of early projects determine future technology, early outcomes also shape legitimacy and cognitive expectations for following projects. This contributes to the paradox of legitimacy: even if technology progresses, it may still suffer from disappointment and legitimacy loss if it does not meet the (potentially unrealistic) hopes that triggered the policy support.

2.3.2. Policy learning and policy feedback

Any policy may change or be cancelled, for technology-internal reasons or reasons external to the focal technology. First, technology legitimacy may change after change in political power that results in shifting technology and policy preference (Thonig et al.,

2021). Such legitimacy change originates in different ideological approaches and thus a different evaluation of the same facts by different policymakers (Thompson et al., 1990). Second, support policy may also experience negative policy feedback (Pierson, 1993; Sewerin et al., 2020), for example if a support scheme is perceived as too expensive; such changes, despite strong technological progress, led to strong reforms of the German renewable power support scheme in 2012, and the cancellation of Spanish feed-in tariffs in 2013 (Gürtler et al., 2019). Third, the policy mix for a focal technology may also be affected by broader trends in policy learning (Bennett and Howlett, 1992). This can be changes in instrumentation or instrument design, e.g. from feed-in tariffs to auctions as the main support instrument, reflecting a shifting political mood for more market-based instrumentation (del Río and Kiefer, 2023).

2.3.3. Changing context alignment

Technological legitimacy may also change when the political context changes (Markard et al., 2016), either through landscape shocks altering the energy or climate policy debate, such as a disaster (e.g. Fukushima meltdown, increasing relative legitimacy of non-nuclear technology (Markard et al., 2020) or through slowly increasing pressure (e.g. increasing knowledge of climate change, raising legitimacy for zero-carbon technologies and infrastructures). Such changes in alignment can also be caused by other technologies: if one technology is successful and start altering the system, it triggers new problems and solution needs, thereby affecting the legitimacy for another (Markard and Hoffmann, 2016). For example, growth of intermittent power triggers a need for storage (Sinsel et al., 2020). Context evolution may also change perceived complementarities (Dahmén, 1988) of different technologies. Losing or gaining new application may fundamentally change the cognitive legitimacy of technologies. For example, high-voltage direct current transmission existed for a long time, but is now widely seen as enabling long-distance transmission of renewable power (Andersen and Markard, 2020), enabling continued and accelerated renewables deployment. One important part of the technological context for one technology is thus how adjacent technologies develop.

2.4. Cross-technology legitimacy feedback

Different maturing technologies form part of each other's socio-technical contexts: deployment of adjacent technologies may thus fundamentally change the context, technological legitimacy, and policy ambition of a focal technologies from t_0 when policy support was first implemented and a subsequent policy evaluation at a later t_1 . Through either positive or negative feedbacks, this will affect policy makers' decision to continue, ratchet up their policy ambition or abandon support (Sewerin et al., 2023). Because financial, cognitive, and administrative resources are limited, policymakers will tend to focus resources on those technologies with the highest legitimacy at the time. Thus, not the absolute legitimacy of a technology is important, but legitimacy *relative* to other solutions to the same problem: higher legitimacy for one technology means lower relative legitimacy of another. The available alternatives are thus an important factor when choosing technological options and designing a support scheme (Bergek et al., 2023).

Building on the argumentation above, we propose that the dynamic, rapid deployment of a successful Technology A at t_0 decreases *relative* legitimacy of a competing but less dynamic, slower-deployed Technology B in the next time step (t_1), either pushing Technology B off political agendas or forcing the technology to change to become complementary and ideally supportive of Technology A.

The success of Technology A creates a feedback effect changing the context, and thus also the context alignment, of Technology B, resulting in legitimacy loss across all three dimensions relative to the dynamic technology. Table 1 holds an illustrative example of two support-dependent technologies with initially different deployment paces and technological progress, which result in diverging technological legitimacy, solidifying the advantage of the dynamic Technology A over the laggard Technology B over time.

Low and decreasing relative legitimacy compared to dynamic Technology A may trigger two different effects for Technology B (Fig. 3). First, it invites to focus resources – attention, money and deployment ambition – on the dynamic Technology A, driving a lock-in into Technology A while leading to further stagnation (or lock-out) of Technology B, including the complete elimination of support. For example, the increasing diffusion of battery-electric vehicles in the EU and elsewhere creates a positive feed-back dynamics in a virtuous *technology-legitimacy-policy* cycle while marginalizing alternatives like fuel cell vehicles (IEA 2022).

Second, policymakers may build on the existing, albeit slower, progress of Technology B and redirect efforts supporting it to other niches or applications not easily served by Technology A. Making Technology B complementary, or even synergistic, to Technology A may thus open new spaces for the laggard option (Sandén and Hillman, 2011). This constitutes a shift in cognitive legitimacy: Technology B is now *doing something else* than before and may adapt some of its technological characteristics. For example, in the early 2000s, CCS was discussed primarily as an abatement option for coal power in the electricity sector (Lilliestam et al., 2012) – a problem, most believe today in 2024, will be better solved with renewables rather than with CCS. Instead, essentially the same CCS technology is emerging in multiple new niches as an industrial emissions abatement option and climbing agendas as a must-have for remote-future

Table 1

Relative legitimacy re-evaluation of a dynamic technology (A) and a laggard technology (B) at t_1 after initially both technologies were included in the policy mix at t_0 .

	Dynamic Technology A	Laggard Technology B
Characteristic	Dynamic deployment, faster technological learning	Slower deployment, slower technological learning
Pragmatic legitimacy	Benefits are visible, safe bet for investments	Short-term benefits are smaller, investments and support riskier
Moral legitimacy	Creates benefits and solves problems	Increasingly unclear long-term benefits
Cognitive legitimacy	Increasingly taken-for-granted	In doubt, possibly useful for another niche
Relative legitimacy	High and increasing	Low and decreasing

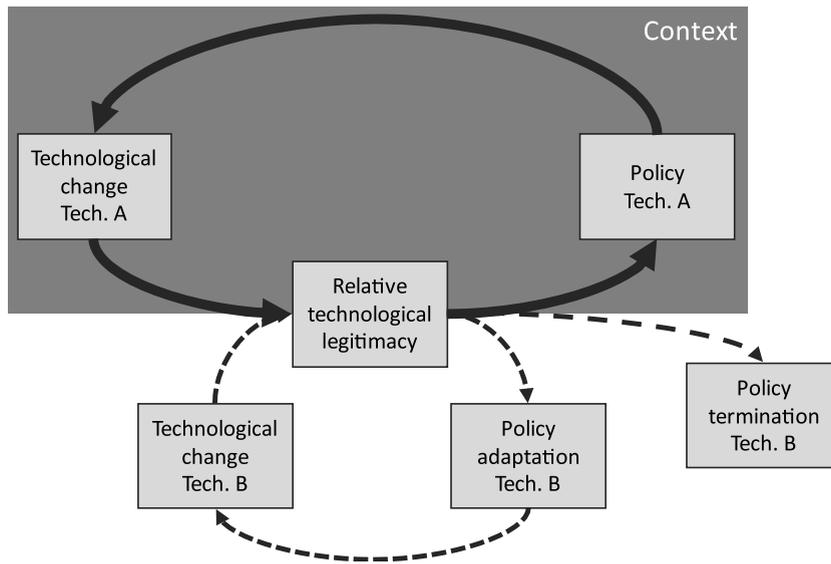


Fig. 3. Cross-technology feedback from the dynamic development of Technology A, affecting the relative technological legitimacy of laggard Technology B through a shift in technology-context alignment. Each iteration of the cycle indicates progressing time. Diverging relative technological legitimacy increasingly affects policy decisions the further Technology A and B grow apart and may lead to adaptations for complementarity or policy termination for Technology B.

negative emissions (Sovacool et al., 2022, Finstad and Dahl Andersen, 2023).

In sum, therefore, we propose that technologies affect the development of each other and that this happens through the development of their relative legitimacy. Technology A affects the legitimacy of itself and thereby also the relative legitimacy of Technology A vs Technology B; this then affects the policy for Technology B, either by reducing/increasing deployment or by altering Technology

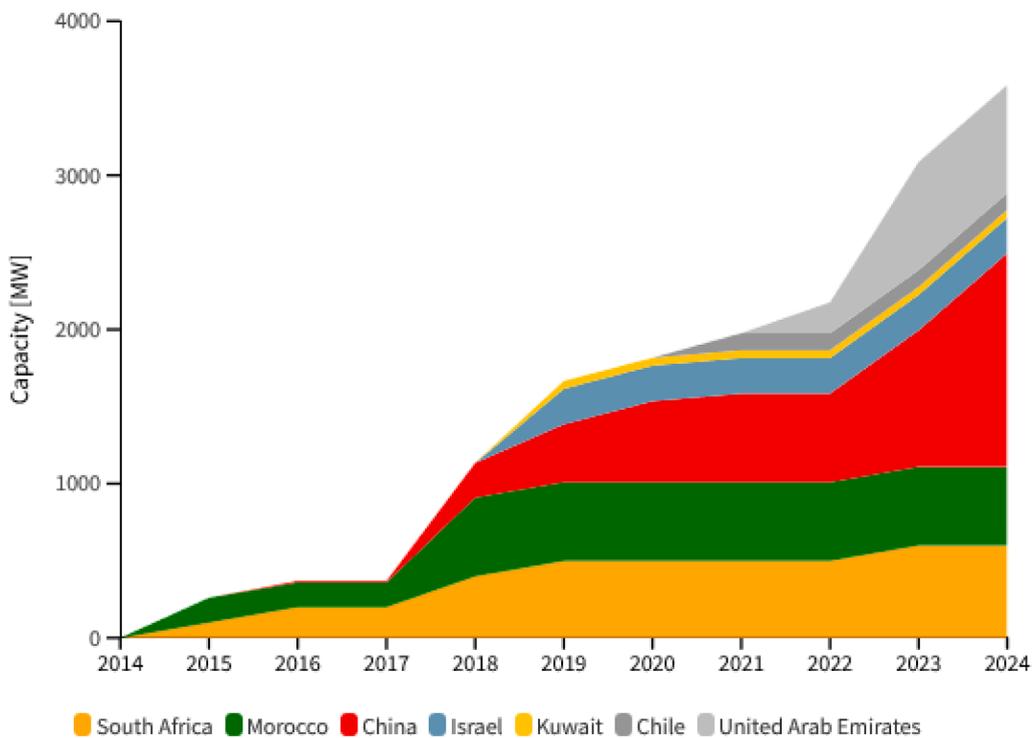


Fig. 4. Global deployment of CSP 2014–2024 in MW. All projects starting construction in or after 2012, when PV became cheaper than CSP globally, are displayed by year of completion or expected completion in 2024 for projects under construction in mid-2023. Source: Ember (2023), Thonig et al. (2023). 4.5GW CSP capacity were previously completed in other places.

B. This would help explain why some technologies disappear although they develop well, in and of themselves: their problem is that another adjacent technology developed even better. In the following, we test this proposition with the case of CSP, which appears to have fallen victim to this mechanism: its costs decreased and performance increased strongly over the last decade, but yet it fell off political agendas in most, or all, countries, because other technologies developed even stronger.

3. Method

3.1. Case study: did the success of PV kill CSP?

Without a doubt, solar PV is one of the largest success stories of policy-led innovation policies in the past decade and may strongly influence other power technologies. Other than solar PV, which uses the photoelectric effect, CSP collects solar heat to power a steam turbine (Lovegrove and Stein, 2021), so it directly competes for the same niche of solar power. Thus, to study cross-technology feedback we investigate CSP support policies, deployment and technology evolution in the 2010s and early 2020s, especially in response to falling PV cost and increasing PV deployment.

The first commercial CSP plants were installed in the 1980s and a second boom occurred in 2008–13 in the lead-markets of Spain and the US. Especially in Europe, this CSP boom was fuelled by the Desertec vision, foreseeing very large imports of dispatchable CSP from North Africa to balance and enable growing PV and wind power shares (Trieb et al., 2012) (Gosens et al., 2021). However, both Desertec and these lead markets collapsed after the 2008 financial crises and the fall-out of the Arab Spring (Schmitt, 2018). Since then, all CSP deployment has happened outside these initial lead markets, moving mainly to China, Morocco, and South Africa (Fig. 4). The CSP technologies improved strongly over the 2000s, with costs decreasing by 68 % in 2010–2021 (IRENA, 2022), driven by larger stations and more mature designs (Mehos et al., 2020). These positive developments would invite accelerating diffusion.

In the early 2000s, CSP was the cheaper of the two solar power technologies. However, as wind power and PV pushed down their learning curves and eventually became regime-scale technologies with self-reinforcing global dynamics (Strauch, 2020), by 2011, they surpassed CSP, which has since been among the more expensive renewable options (IRENA, 2022).

Consistent with our theoretical proposition (Section 2.4), this may have changed the context for CSP by changing its relative legitimacy compared to PV and wind power, thus affecting the political case for continued policy support and subsequently further CSP investment decisions. The resulting CSP slow-down coincided with the shift in cost-ranking between CSP and PV, suggesting negative cross-technology feedback and decreasing CSP legitimacy vis-à-vis PV may have been important in pushing CSP off political agendas around the world. Yet, techno-economic modelling continues to highlight the value of developing CSP with thermal energy storage, not for bulk generation but for flexible, dispatchable generation to complement intermittent sources (Schöniger et al., 2021; Kennedy

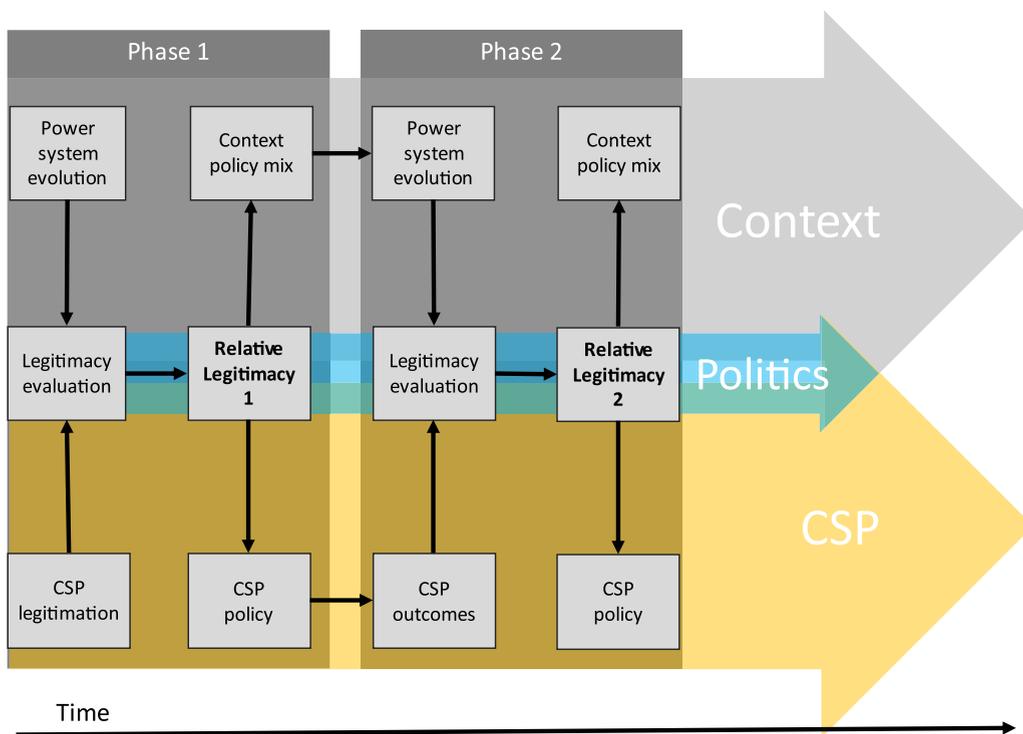


Fig. 5. Analytical framework: to evaluate factors influencing the interpretation of technological legitimacy evolution of CSP over time, we observe the system context and CSP-specific policy output and technology outcomes when support decisions were implemented.

et al., 2022; Resch et al., 2022). In the following, we empirically test our proposition for three national CSP cases.

Indeed, CSP deployment stagnated over the 2010s, with only a few hundred MW connected to the grid annually, and only in a few countries (Lilliestam et al., 2021). Since 2012, 37 commercial-size (>10 MW) CSP plants started construction, all under a national policy support scheme (Thonig et al., 2023). Of these 22 are in China, 7 in South Africa, 3 in Morocco, and 5 in other countries (Fig. 4); we focus our analysis on these three countries, both because this is where active CSP policy existed in the 2010s and, to test our proposition, all three subsequently appear to have abandoned or strongly changed their CSP support. Since we are interested in policy feedback and adaptation over time, we exclude the singular projects in other countries, specifically one in Chile, Kuwait and the UAE, as well as two Israeli plants originally developed under a 2008 policy and completed in 2019 after long delays. The projects in the three investigated countries represent 1.7 GW CSP, or about ¼ of the total global CSP capacity in 2022 – and all places with new projects breaking ground since 2020 (China, and South Africa). These three case studies are thus well representative of the global policy and technology trajectory in the last decade.

3.2. Assessing cross-technology legitimacy feedback

In the following, we observe technology legitimacy as interpreted by the policymakers deciding on introduction, adaptation or cancellation of a support scheme, by exploring factors informing this decision: the system context (including problem definitions and development of adjacent technologies), CSP and other deployment policies and their goals, as well as the technology outcomes these policies produce. For all three countries, we build narratives based on national policy documents, academic articles, and power sector statistics. A central observation is the policy output of each country (over several cycles), which represents the result of the political process at the beginning of each cycle. We do not investigate the political process of each country, for example as expressed in parliamentary debates, as this would not add depth for analyses of non-democratic countries. For consistency, and because the national energy policy debate is similarly opaque as in the other cases, we also base our analysis of South Africa, which is a democratic country, on the policy output and not on direct policy process observations. Technical data are based on the csp.guru dataset (Thonig et al., 2023); the method for the csp.guru data collection was described in (Lilliestam et al., 2017; Lilliestam et al., 2021). All cost data is expressed as USD₂₀₂₀.

As described above (Section 2.4), we expect to see at least one of two developments indicative of negative cross-technology feedback. First, indicative of relative CSP legitimacy decline vis-à-vis other renewable power technologies, we expect to observe disappearing CSP policy support and decreasing (or disappearing) expectations of its future role, accompanied by an increasing emphasis of more dynamic technologies in both policy support and visions. Second, a shift in cognitive legitimacy, indicated by changing CSP policy design, explicitly remunerating dispatchable power (e.g. time-of-day pricing, capacity pricing) to ensure that it grows complementary to cheaper but intermittent renewables. This would also be observed as changing CSP technology outcomes, with stations designed with larger storage and adapted generation profiles to fit the dispatchability requirements of the support.

Table 2

Narrative elements for analysis of CSP legitimacy narratives, for each step of Fig. 5.

Dimension	Characterised by:
Context	Context policy mix: <ul style="list-style-type: none"> - High-level national strategies for economy, environment - Other national priorities relevant for the power sector - National political system and institutional set-up for decision-making in the power sector - External events and decisions influencing renewable energy policy Power system evolution, especially PV and wind power <ul style="list-style-type: none"> - Development of the energy mix: installed capacities of CSP vis-à-vis other generation options - Relative cost: power price of CSP vis-à-vis other options
CSP policy output	Policy ambition and intention <ul style="list-style-type: none"> - Announced CSP projects - Relative long-term ambition/targets of CSP compared to other technologies, especially PV and wind - Intended role of CSP in the future power system Policy instruments and their design <ul style="list-style-type: none"> - Feed-in tariffs and their conditions - Auction schedule and decision-making schedule: when was a project awarded; auction outcome, signatures of PPAs - Concessional financing or loans - Storage requirements, possibility for hybridisation - Remuneration for dispatchability, time-of-day pricing
CSP technology outcome	Technology and design of awarded CSP projects <ul style="list-style-type: none"> - CSP reflector geometry: Trough/tower/Fresnel/beam-down - Thermal energy storage (TES) duration (hours of full-load operation of turbine) - Solar multiple (Size of solar field compared to capacity of the power block) approximately $SM\ 1 = 6000m^2 / MW_{CSP}$ (Trieb, Schillings et al., 2009) - Hybridisation capacity ratio with other (Wind, PV, etc.) power sources (MW_{Other}/MW_{CSP}) Project dynamics <ul style="list-style-type: none"> - timely commercial operation - deadline extensions, project termination, etc. - Project performance

To illuminate the path-dependent co-evolution of CSP with other renewables we construct CSP centric *narratives of the niche-innovation trajectory* (Verbong et al., 2008), in the case study countries focusing on how the CSP trajectory was impacted by its own performance (within-technology feedback) and the cross-technology feedback from other technologies, mainly PV and wind power. This follows the ideas of process theory (Abbott 1992) to describe fuzzy and unfolding processes such as the path-dependent enactment of a policy pathways and its technology outcomes as a sequence of events and decisions. Here, we develop and condense chronologies (Verbong et al., 2008) of CSP development, focusing on the cross-technology feedback.

We structure the narratives as a sequence of cycles with distinct phases (Fig. 4), where (relative) legitimacy assessment happens in the agenda setting/evaluation phase (initially at t_0). This is followed by policy formulation, influenced by the legitimacy assessment (esp. the cognitive legitimacy, *what type of CSP do we need and for what?*) and triggering a particular technology outcome aligned with the requirements of the policy as formulated, that is subsequently evaluated, before the next cycle begins at t_1 (and so on to t_x). As mentioned above, we evaluate CSP-specific policy output as reflections of policymakers' evaluation of CSP legitimacy at the time these policies are decided. We do not investigate the political and bargaining process in any detail, but merely the results of these process as observed in the policy output. Changes in legitimacy evaluation may thus lead to changed policy instruments or design, which in turn produces different technology outcomes as developers react to the new policy incentives. In the final step, CSP technology outcomes are re-evaluated against their own goals *and* relative to the performance of other technologies. This legitimacy then feeds into the policy formulation of the next cycle at t_1 (and subsequent cycles).

We build the narratives around elements describing the socio-technical context, including development of adjacent technologies, CSP policy output, and CSP technology outcome (Table 2). For each legitimacy evaluation point, starting each cycle, we synthesise the narratives along the lines of the three legitimacy dimensions, assessing whether CSP is in the self-interest of policymakers (pragmatic), what function CSP is perceived as fulfilling (cognitive) and whether it is perceived as the right thing (moral). We do this for CSP ([intra-]technology feedback) and CSP relative to other technologies (cross-technology feedback), primarily wind power and PV.

4. Results

4.1. South Africa

In South Africa, the *Renewable Energy Independent Power Producer Procurement Program* (REIPPPP) triggered substantial PV and wind power expansion, but also notable CSP deployment (Fig. 6). We find three distinct CSP policy phases. Under REIPPPP bid windows (BW) 1–2, CSP was considered an important renewable option. First projects were successful and competitive with PV, although subsequent cost reductions could not keep pace. Second, in BW3–4.5, time-of-day pricing was introduced to steer CSP generation to the valuable evening peak hours, resulting in larger-storage plants. In a third phase, CSP-specific support was abandoned as too costly.

4.1.1. Phase 1: commercial CSP demonstration

Context: The South African power system is operated by the integrated utility Eskom (Ting and Byrne, 2020). Growing demand paired with underinvestment, corruption, and cost overruns for new power stations have resulted in a continuous electricity crisis with load shedding since 2007 (Rathi, 2022). Thus the government launched long-term capacity planning in Integrated Resource Plans (IRP) and the instated the REIPPPP programme (RSA 2005; RSA 2006).

Policy output: In the first IRP, adopted in 2010, 1.2 GW CSP was part of the procurement portfolio, which also held 6.3 GW coal,

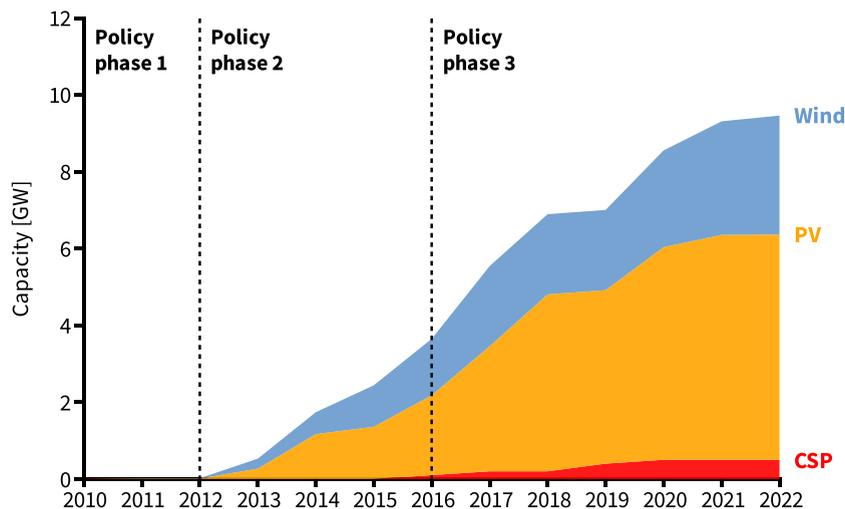


Fig. 6. Renewable capacity additions in South Africa 2010–2022 and CSP policy phases. Capacities may only come online in a later policy phase due to construction time and delays. No new CSP projects were awarded after 2015 in phases 3–4. Data: Ember (2023), Thonig et al. (2023).

9.6 GW nuclear, 8.4 GW PV & wind, respectively, to be completed by 2030. The first two auction rounds of the REIPPPP program (BW1–2) opened in 2011 (Eberhard and Naude, 2017) aimed to procure 3.4 GW of wind and PV, but also 200 MW CSP. The auctions were open to international developers to attract the latest technology and aimed to ensure domestic job creation through local content requirements (RSA 2011). Simultaneously, Eskom pursued its own 100 MW Kiwona CSP project (Swilling, 2019), which secured \$350 million multi-lateral concessional financing from donors looking to help South Africa reduce carbon emissions (Worldbank, 2011).

Tech outcome: In December 2011, BW1 awarded 150 MW CSP in two projects in Northern Cape followed by one project from BW2 in May 2012 (Table 3), together with over 1000 MW of wind and PV, respectively. All CSP projects secured financing and commenced construction, using the latest European CSP designs and delivered first power in 2015, demonstrating the feasibility of CSP in South Africa. All IPP projects, especially Bookport, include storage to maximise the utilisation of the fixed auctioned capacity (Table 3). Eskom's Kiwona CSP, in contrast, did not start construction.

4.1.2. Phase 2: CSP policy adaptation for dispatchability in the IRP 2013 and REIPPPP BID windows 3, 3.5, 4 & 4.5

Context and legitimacy effects from Phase 1: While the first successful projects and observed cost reduction bolstered CSP pragmatic legitimacy, stronger cost reductions of PV and wind undermined it: in BW1, CSP was on average cheaper per kilowatt-hour than PV, but not from BW2. While CSP costs decreased by 16 %, PV costs fell by 46 % and CSP support cost became a disproportionate share of policy cost (Table 4). Evaluating these developments, the draft IRP (2013) suggested to increase wind and PV ambition but makes an increase of CSP targets to 3.3 GW by 2030 conditional on additional cost reduction (Helios CSP 2014).

Policy output: Building on the dynamic deployment of renewables, additional tenders for 3200 MW renewables were announced in 2012 (RSA 2012), including 400 MW CSP. To address the emerging CSP cost concerns, BW3 introduced time-of-day pricing to incentivise dispatchable CSP generation during high-value peak demand hours (Silinga et al., 2015), granting CSP generation between 4.30–9.30pm 270 % of the strike price, but no payment at night (10pm–5am) (Relancio et al., 2016). This rule was also applied to the 200 MW CSP tendered in the CSP-only BW3.5. BW4 contained no CSP.

Technology outcome: BWs 3–3.5 led to the completion of four additional CSP projects in Northern Cape (DoE 2014). The technology outcome reflects the new policy design: all plants have five or more hours storage to receive the evening peak remuneration and much lower cost compared to previous projects (Table 5).

4.1.3. Phase 3: contestation and discontinuation of CSP deployment

Context and legitimacy effects from Phase 2: Legitimacy of all renewables increased with the success of the REIPPPP program: capacities were completed much faster than Eskom's coal projects and costs were decreasing, especially for PV and wind. Including the peak generation bonus, CSP strike prices decreased by 60 % from BW1 (Eberhard et al., 2014; Relancio et al., 2016; Larmuth and Cuellar, 2019). However, renewable tenders were halted in 2016, reflecting changes in the political leadership and technology legitimacy evaluation. Instead of renewables, the draft IRP (2016) focused on procuring nuclear reflecting a presidential deal with Russia (DoE 2014b). Moreover, when new coal capacity interrupted load shedding (DoPE, 2016), Eskom announced that further IPP projects were not needed and refused signing already awarded projects, including Redstone and all other BW4 projects (Moyo, 2016). Renewable power fortunes shifted again after the High Court declared the nuclear deal unlawful (Roelf, 2017), and another restructuring of the government (Winkler, 2018). The new minister decided to review energy policy to minimise cost and quickly increase power supply to address renewed blackouts.

Output: The halted BW4 PPAs were signed with years delay only in 2018 and the new IRP (2019) held 6800 MW of only PV and onshore wind for 2022–2024, alongside 1500 MW new coal (RSA 2020). The nuclear plans were declared unaffordable and postponed by 10 years (Khumalo, 2018). Both the nuclear-focused draft IRP (2016) and the latest IRP (2019) exclude additional CSP after BW4.5 (Duvenhage et al., 2018), arguing that only low-cost technologies are needed.

Technology outcome and context evolution: The commissioning of Redstone, expected in 2023 (from BW3.5 in 2014), preliminarily marks the end of CSP deployment in South Africa. In BW5, PV is 95 % cheaper than in BW1 and only 25 % of the lowest CSP strike price (Table 4) (DMRE 2021). The trend away from CSP is also reflected in Eskom's decision to change the Kiwona CSP project to 360 MW/1440 MWh PV + battery (NERSA 2021).

4.2. Morocco

In Morocco, CSP has been a priority technology – and Morocco is the only country with more CSP than PV capacity (Fig. 7). We find three phases marked by separate projects. In the first, CSP was introduced with royal blessing, pushed by international collaboration, but at high subsidy cost. Successful project execution legitimised a second phase, for dispatchable CSP, still dependent on subsidies. The third phase saw both further policy and technology adaptation to become subsidy-independent through hybridisation with PV, but

Table 3

CSP technology outcomes of Phase 1 in South Africa. Data from: Eberhard et al. (2017), Thonig et al. (2023).

Policy	CSP Tech	Project name	Capacity MW	Hybridisation	Storage hours	CAPEX \$/kW	Solar multiple	Time: Bid, Operational
BW1	PT	KaXu	100	0	2.5	9030	1.3	2011, 2015
	DST	Khi	50	0	2	9330	1.9	2011, 2016
BW2	PT	Bookport	50	0	9.2	11,700	1.9	2012, 2016

Table 4

Outcomes of BWs 1–6 for CSP, wind power and PV in the REIPPP. We aggregate the CSP-only BW 3.5 with the no-CSP window 4, which had two batches of preferred bidders announced (a and later b). As BW4.5 expired without any awards, it has no strike prices. Data: Eberhard et al. (2014), Eberhard and Naude (2016), Eberhard and Naude (2017), DMRE (2021), DMRE (2022).

REIPPPP BW and submission date	Average strike price \$/kWh and reduction compared to BW1			Capacity awarded MW of offered and share of awarded				Total investment cost share			
	CSP	PV	Wind	CSP	PV	Wind	Other	CSP	PV	Wind	Other
Phase 1											
BW1 11.2011	0.32	0.33	0.14	150/ 200 11 %	627/1450 44 %	649/1850 45 %	0/126 0 %	24 %	48 %	28 %	0 %
BW2 03.2012	0.27 -16 %	0.18 -46 %	0.096 -29 %	50/50 5 %	417/450 40 %	559/650 54 %	14/ 126 1 %	16 %	43 %	39 %	2 %
Phase 2											
BW3 08.2013	0.15 -52 %	0.092 -72 %	0.069 -49 %	200/ 200 14 %	401/435 30 %	787/654 54 %	35/ 218 2 %	40 %	18 %	38 %	3 %
BW3.5 (CSP- 03.2014) & 4a, b (PV, Wind) 05.2014	0.13 -60 %	0.071 -78 %	0.060 -55 %	200/ 200	415+398* /400	676+686/ 590	30/ 115	31 %	25 %	42 %	2 %
Phase 3:											
BW 4.5 11.2015 (expired)	–	–	–	0/450 0 %	0/520 0 %	0/650 0 %	0/170 0 %	0 %	0 %	0 %	0 %
Phase 4											
BW 5 08.2021	–	0.030 -91 %	0.035 -74 %	0/0 0 %	975/1000	1608/1600		0 %	n.k.	n.k.	0 %
BW 6 03.2022	–	0.033 -90 %	–	0/0 0 %	860/1000 100 %	0/4200 0 %	0/0	0 %	100 %	0 %	0 %

Table 5

Technology outcomes of BW 3 & 3.5 Data: Thonig et al. (2023) (*expected completion as Redstone is under construction at the time of writing).

Policy	Project name	Capacity MW	Technology	Technology origin	Storage hours	CAPEX \$/kW	Solar Multiple	Bid, Operational
BW3	Xina	100	Trough	Spain	5	8950	1.4	2013,2017
BW3	Illanga	100	Trough	Spain	6	7250	1.5	2013, 2018
BW3.5	Kathu	100	Trough	Spain	5	9180	1.8	2014,2019
BW3.5	Redstone	100	Tower	USA	12	7737	1.8	2014, 2023*

also a de facto construction stop.

4.2.1. Phase 1: commercial CSP demonstration: the Moroccan solar plan and Noor 1

Context: During the 2008 oil price spike, the Moroccan government decided to diversify the independent power producer (IPP) program towards renewables (Choukri et al., 2017), to reduce costly imports. In 2010, it set a goal of 42 % renewable capacity by 2020 (Cantoni and Rignall, 2019). This step coincided with the *Desertec* vision, which sought to realise CSP exports from North Africa to Europe (Trieb et al., 2012; Schmitt, 2018) and saw its first projects in Morocco. The emerging renewables sector tentatively offered industry development and jobs.

Policy output: King Mohammed VI launched the Moroccan Solar Plan in 2009 and founded the Moroccan Agency for Solar Energy (MASEN) to build 2000 MW solar by 2020 (Loi no 57–09, 2010). Expanding wind and hydropower was left to the Office National de l'Eau et de l'Electricite potable (ONEE), the vertically integrated national grid operator. MASEN's first project was Noor-1 in Ouarzazate (Aqachmar et al., 2019). The government agreed to finance the difference between the power price paid by ONEE (\$0.09/kWh) and the PPA signed with the IPP. The potential for more local jobs and the ability to deliver power after sunset were important arguments to choose CSP.

Tech outcome: The plant was awarded in 2012 to a consortium led by ACWA and three Spanish CSP companies at \$0.16/kWh, almost double the regular grid tariff. ONEE signed the PPA, and ACWA achieved financial close including concessional finance guarantees by international development banks (Frisari and Stadelmann, 2015). Construction started in 2013 (Tardy and Lu, 2014). The plant uses Spanish technology, including parabolic troughs, wet cooling, and a 3-hour storage (Table 6-Phase 1).

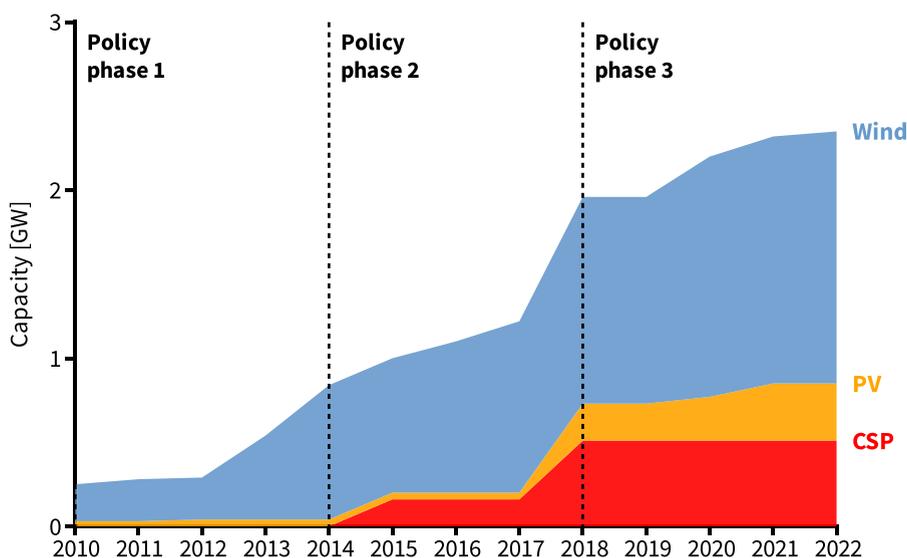


Fig. 7. Phases of CSP policy in Morocco and renewable capacity additions 2010–2022. CSP capacity has remained constant since 2018. Data from Ember (2023), Thonig et al. (2023).

4.2.2. Phase 2: CSP policy and technology adaptation for storage at Noor-2 and 3

Context: In 2013, the Desertec vision dissolved and with it the prospects of imminent CSP exports from Morocco (Calderbank, 2013; Schmitt, 2018). Nevertheless, CSP legitimacy remained high. In the run-up to the 2016 climate conference in Marrakesh, the King personally opened Noor-1. The project – the first CSP station in a developing country – was seen as a great success. This led to an expansion of MASEN’s mandate to also include wind and hydropower projects. Subsequently, the 2030 renewables target was increased to 52 % of installed capacity (Cantoni and Rignall, 2019).

Policy output: In 2014, Masen issued another tender for two CSP plants in Ouarzazate. Despite criticism of the high cost of Noor-1, the technology choice was justified with the ability of CSP to produce peak power, fitting the Moroccan system well, and a higher job-creation potential vis-à-vis PV. To ensure high dispatchability, the tender included a minimum storage duration of 7 h. International concessional financing and the financial coupling of both projects’ financials were prepared to allow the best possible outcome.

Technology outcome: The parabolic trough Noor-2 showed some improvements compared to Noor-1 with lower cost despite the larger storage (Table 6). Noor-3, in contrast, was a world-wide first-of-a-kind molten-salt tower and used dry cooling to minimise water usage in the desert town. Again, project execution was unproblematic, and both units were connected to the grid in 2018. (Table 7)

4.2.3. Phase 3: adaptation of CSP policy for hybridisation with PV

Context: The awarded bids for Noor-2 & 3, both \$0.14/kWh, were 15 % lower than for Noor-1, but with the completion of the first project, the cost of the subsidy became visible. Moreover, the CSP PPAs signed in 2015 were almost five times higher than the average bid of \$0.03/kWh for the 850 MW wind signed by ONEE in 2016, and three times the strike price of Noor-PV1 (including Noor Ouarzazate 4, collocated with the CSP plants) (Green Giraffe, 2016).

Policy Output: MASEN continued to develop its next big CSP project near Midelt. Responding to cost concerns, it chose a PV-CSP hybrid design, “enabling supply of electricity after sunset while providing a low-cost solution for daytime generation” (Masen, 2015). The tender for Midelt 1 sought a 150–190 MW CSP component coupled with 150–210 MW PV, requiring the unit to produce at least 160 MW for 5 h after sunset (Ginger Phenixa, 2019). As in Ouarzazate, Noor Midelt draws on international concessional financing (Worldbank, 2017).

Tech Outcome: The winning bid (\$0.07/kWh) announced in 2019 cut the Noor-3 strike price in half and went below the on-grid power cost, making government subsidies obsolete. The technological outcome was entirely different from the plant configuration intended in the request for proposals. The inclusion of electric heating for the thermal storage minimised the CSP solar field and substituted it with cheaper PV, tripling the PV capacity compared to the tender (Reuters Events, 2019). Indeed, the parabolic trough

Table 6

CSP technology outcomes in Morocco of Phase 1,2 and 3. Data from Thonig et al. (2023).

Phase	CSP tech	Project name	Capacity MW	Hybridisation	Storage hours	CAPEX \$/KW (CSP)	PPA \$/kWh	Solar multiple	Time: Bid, Operational
1	PT	Noor-1	160	0	3	7589	0.16	1.4	2012,2015
2	PT	Noor-2	200	0	7	5596	0.14	1.5	2015, 2018
	MST	Noor-3	150	0	7	5847	0.14	1.5	2015, 2018
3	PT	Noor Midelt	200	600 PV	5	4225	0.07	0.2	2019, -

Table 7Technology outcomes during Phase 1 and Phase 2 during the 13th FYP. Based on [Thonig et al. \(2023\)](#).

Policy	CSP Technology	Capacity MW (# of projects)	Hybridisation-capacity- ratio (PV+wind)/CSP	Storage (range)	CAPEX \$/kW Average	Solar multiple Average	Time	Tariff \$/kWh
Phase 1 & 2: First demo batch (completed)	4 MST, 2 PT, 1 LFR, 1 BDT (8/20)	100 (2), 50 (6)	0	12.6h (6–15)	4589	2.34 **	2016–2018 (-21)	0.16
Multi-energy demo	1 MST	50	12 (200 PV, 400 Wind)	12	3315	2.0	2017- 19	n. k.
Phase 3:	8 MST 2 LFR	100 (9) 110 (1)	6 (5), 9 (4), 10 (1)	8, 12	2200	0.9	2021–2025	0.05

** excluding the beam-down tower project which only completed a part of its solar field.

PR=Parabolic trough, MST= Molten salt tower, LFR=Linear Fresnel, BDT=Beam-down tower.

field is only 13 % the size of Noor-2, although both turbines are 200 MW, implying a solar multiple of just 0.2.

Context evolution: In 2020, the national watch dog *Conseil Economique, Social et Environmental* evaluated the success of the renewable power program (CESE 2020). It criticised the high subsidy of \$80 million/year for Noor 1–3 in the face of cheaper PV and wind and recommends that CSP is abandoned. Since then, the Noor Midelt 1 project was delayed based on reliability and cost concerns for CSP, both within ONEE and the energy ministry ([Eljechtimi, 2024](#)), further indicating the currently low CSP legitimacy in Morocco.

4.3. China

Over three five-year plans (FYP) in 2006–2021, China diversified power generation from coal by deploying novel technologies and expanding their national supply chains. CSP arrived late, taking off during the 13th FYP in 2016. The first CSP phase 2016–18 envisaged rapid growth and sought to develop a Chinese CSP industry. It was followed by brief stagnation in 2018–2021. In the 14th FYP, from 2021 a new phase of subsidy-free renewables deployment began, and new types of hybrid projects emerged, where CSP is deployed as a long-duration storage technology, embedded in gigawatt-scale PV and wind farms. ([Fig. 8](#))

4.3.1. Phase 1: commercial CSP demonstration in the 13th five-year plan

Context: In the 11th and 12th FYP (2006–2015), China successfully built a domestic PV industry, first based on deployment in foreign markets and then, as support in export markets decreased, in a national support scheme ([Quitow, 2015](#); [Nemet, 2019](#)). Going into the 13th FYP, China sought to build further globally leading manufacturing industries, also in renewable energy ([State Council 2015](#), [Gosens et al., 2017](#)). The global CSP market downturn since 2011 offered a chance for Chinese industry to catch up to Western designs, building on several previously completed demonstration projects ([Gosens et al., 2021](#)).

Policy output: A national CSP industry was to be supported by deploying 5 GW CSP over five years ([NEA 2016](#); [Lilliestam et al., 2019](#)). An initial 1.35 GW in 20 commercial-scale demonstration projects were to be completed by 2018, for which the national feed-in-tariff was amended to remunerate CSP at \$0.18/kWh ([CSTA 2015](#)). The projects were selected for diversity across regions and

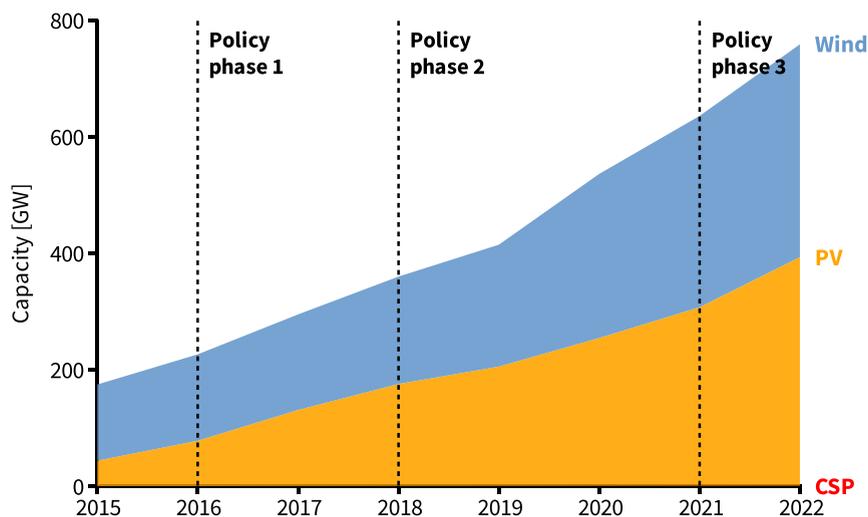


Fig. 8. Phases of CSP policy and deployment of wind power, PV and CSP in China, 2010–2022. CSP capacity is three orders of magnitude smaller and barely visible. Source: [Thonig et al. \(2023\)](#).

technologies (NEA 2016). In parallel, a separate policy aimed to test the complementarity of several renewable technologies, by adding storage options and dispatchable renewables, also including CSP (Wang et al., 2017).

Technology outcome: By the 2018 deadline, only 3 projects were grid connected, with 5 more under construction (Thonig et al., 2022). The first completed project, CGN Delingha 50 MW trough, used proven European technology (SBP 2021) and received international concessional funding (ADB 2022). The other two were Chinese-designed molten-salt towers, based on previous demonstration plants (Thonig et al., 2022). The Luneng Haixi multi-energy project, which was not part of the demonstration programme, is technologically entirely different, co-locating 50 MW CSP with 400 MW wind power, 200 MW PV and a large battery.

4.3.2. Phase 2: competition from other renewables

Context: From 2016, the 13th FYP triggered a PV and wind power boom. Developers rushed to claim limited government funds and the 2020 PV goal was met already in 2017. The national feed-in tariff was quickly oversubscribed, so that 90 % of the renewables projects did not receive timely compensation (Energy Iceberg, 2020; Song et al., 2022). In contrast, CSP expansion was slow – less than half the projects of the demonstration programme had started construction at the 2018 deadline.

Policy output: The low completion rate of the demonstration batch had several effects. First, no further batches were announced (NDRC 2021) despite strong CSP industry interest with some 15 GW under development (Protermosolar, 2019). Second, the 2018 completion deadline was extended (SolarPaces, 2018), but the FIT was reduced as a penalty (CSP Plaza, 2021). Yet, projects completed in 2019 or 2020 had to wait for remuneration (CSTA 2020) until decisions on FIT eligibility and payments arrived in 2021; the updated rules excluded CSP projects connected after 2021 (NDRC 2021b).

Technology outcome: As the lacking clarity of the FIT made financing and permitting difficult, no new projects broke ground after 2018 (CSP Plaza 2017), but 4 further projects were completed. Thus, some technical goals of CSP demonstration were met. Chinese designs were proven at utility-scale, with several plants quickly performing as expected (CSTA 2022b; CSTA 2022a; Cosin Solar, 2023), and the industry grew and can deliver several GW CSP per year (CSTA 2022a). In international comparison, the Chinese CSP projects are cheaper (\$4500/kW on average) and hold larger storage (average 12.6 h) and solar multiples (2–3).

4.3.3. Phase 3: shift to CSP as storage

Context: The 13th FYP saw an unprecedented renewables boom, overshooting the FYP goal for wind and PV (Table 8). In contrast, CSP only achieved 10 % of its intended capacity. Moreover, in 2021, most of the technical potential for solar PV reached grid-parity with coal (Lu et al., 2021), which changed the politics of PV by allowing for subsidy-free deployment and cancelling the underfinanced and oversubscribed FIT system (CSTA 2022a). However, the large-scale renewables deployment started to create problems of curtailment and grid congestion (Wang and Wang, 2022).

Policy output: The national FIT for CSP projects completed after 2021 was terminated along with the FITs for all other renewables (NDRC 2021b). The 14th FYP has no dedicated CSP support, but promotes new large-scale multi-energy complexes with storage, including CSP as an option for meeting storage quotas in "solar+" projects (NDRC 2021a, NEA 2022). Moreover, the 14th FYP on modern energy systems set provincial CSP goals in Qinghai, Xinjiang, Gansu, and Inner Mongolia, for 2.75 GW by 2025 (CSP Plaza 2022). Since 2021, provincial remuneration for grid-parity projects is oriented at the provincial coal power tariffs; in Xinjiang, for example, this is \$0.04/kWh (NEA 2022b), 20 % of the CSP FIT. Future Chinese CSP deployment will thus be a product of the storage obligation, rather than of economic support.

Technology outcome: Over 30 CSP projects were announced in 2023, featuring molten salt towers as the dominant choice, but as projects evolve continuously, the technical details, cost and realisation outlooks are uncertain. Several projects combine 50–100 MW CSP with several hundred MW PV or wind, achieving hybridization ratios of 8–12 MW renewables per MW of CSP. Storage capacities range from 8 to 12 h, with emphasis on 8-hour projects. CSP CAPEX has halved to \$2200/kW on average, reaching \$1000/kW for the most PV-heavy hybrid plants with small solar fields and solar multiples below 1. Thus, the CSP projects in planning and under construction in 2023 function as storage units, utilizing concentrated solar heat for only a fraction of generation.

4.4. Synthesis: cross-technology feedback and legitimacy effects

In all three case studies, we find a similar pattern of CSP legitimacy reflected in policy output and technology outcomes consistent with negative cross-technology legitimacy feedback. Initially, CSP was legitimised on its own merits, deployed in a protected niche experiencing positive cost and technology development with slightly different cognitive legitimacy across cases. Subsequently, CSP experienced strong negative cross-technology legitimacy feedback, particularly from PV and wind power, resulting in adapted CSP

Table 8

Goals and realisation of wind and PV compared to CSP (IEA 2021a). Both PV and Wind overachieved targets, while CSP did not reach its goal in the 13th FYP. In the 14th FYP there are no technology specific capacity goals.

	11th FYP 2006–10		12th FYP 2011–2015		13th FYP 2016–2020	
	Target GW	Realised GW	Target GW	Realised GW	Target GW	Realised GW
Solar PV	0.3	0.86	21	43	105	253
Wind	10	31	100	131	210	282
CSP	0	0	0	0	5	0.5

policy, eventually shifting the technology towards complementarity with PV or to policy termination. (Fig. 9)

In both South Africa and Morocco, the first policy phase described CSP *cognitive legitimacy* as a renewable power technology and as a main pillar of a clean and affordable future power system that should be developed and supported with subsidies. Renewable IPP projects had high *moral and pragmatic legitimacy* to address South Africa's power sector problems, whereas in Morocco CSP was an integral part of the *Desertec* vision which enjoyed high moral legitimacy to turn Morocco into a green power exporter and generate cheap domestic power. Moreover, international donors offering financing CSP also lent high *pragmatic legitimacy* to the technology. China, by contrast, framed CSP deployment as a market to conquer (*moral legitimacy*), with good chances to catch up to a stagnating world-market (*pragmatic legitimacy*).

In all three cases, there were subsequent positive developments strengthening CSP legitimacy. First projects, involving knowledge from lead markets, established *cognitive legitimacy* of CSP as a functioning power technology in each national context and an emphasis on local content helped launching a nascent CSP TIS in all three cases. This also strengthened the pro-CSP coalitions and the expectation of continuously decreasing future costs increased both the *moral legitimacy* of CSP as an improving technology and the *pragmatic legitimacy* to continue building on the current success, as showcased by the decision to invite the world to the opening of Noor-1 and construction of further CSP projects in Morocco and South Africa.

In all three cases, however, CSP subsequently experienced negative *cross-technology legitimacy feedback*, particularly from PV and wind. Despite demonstrated success, CSP expansion was slowed down by the even larger success and increasing attractiveness of especially PV. In South Africa and Morocco, the high cost of CSP vis-à-vis renewable alternatives eroded *pragmatic legitimacy* due to availability of a technology better meeting the hopes initially placed in CSP, resulting in calls to abandon the CSP technology route and focus subsidies on the more promising PV and wind. In both countries, CSP developed a *cognitive legitimacy* as a too expensive renewable technology creating pressure to reduce subsidies. Also in China, the resource competition with the dynamic PV expansion in the oversubscribed feed-in tariff system directly increased financial risk for CSP project developers, strangled deployment and led to slower technology progress and deployment, as investments were directed to the cheaper and better-known PV and wind (*pragmatic legitimacy*) that quickly overachieved deployment goals and experienced ever larger ambition.

In response to *cross-technology legitimacy feedback* CSP policies were adapted in all three cases. The first step was to incentivise dispatchability and maximise CSP value vis-à-vis other renewables. Later projects were hybridised to address cost concerns. In South Africa and Morocco, the policy design was adapted to incentivise power production from storage during evening peaks, but both countries focused their renewable strategies on cheap kilowatt-hours. Subsequently, South Africa became the only of the three countries where CSP expansion has been explicitly terminated, largely due to negative cross-technology legitimacy feedback. In Morocco, deployment appears de facto halted. In both cases, high cost of the actual realised CSP stations compared to wind power and PV made it fall out of both plans and policies.

In China CSP transformed to become a storage technology in multi-energy projects combining large PV and wind farms with CSP components. Here, additional *moral legitimacy* arose from the ability to address the emerging intermittency and curtailment issues caused by the success of PV and wind in China. These projects thus complete the transformation of CSP *cognitive legitimacy* from competitor to complement and enabler of PV. Consequently, CSP now competes with other storage technologies that experience *positive* cross-technology legitimacy feedback from PV rather than with renewable generation technologies, which effectively acts as a negative feedback for CSP. The technological improvements and cost reductions of Noor-Midelt and the Chinese projects have yet to spread to new markets and remain nascent, so it is too early to say that CSP successfully navigated into a new niche – but it retains a chance of a renewed virtuous legitimacy-policy-technology feedback-cycle.

5. Discussion

In this article, we proposed negative cross-technological legitimacy feedback as a causal mechanism to help explain why some maturing technologies, despite showing strong technological progress and fast cost reduction, fall off political agendas and subsequently stagnate or disappear. We showed empirically for the case of CSP policy and development in three countries that technological

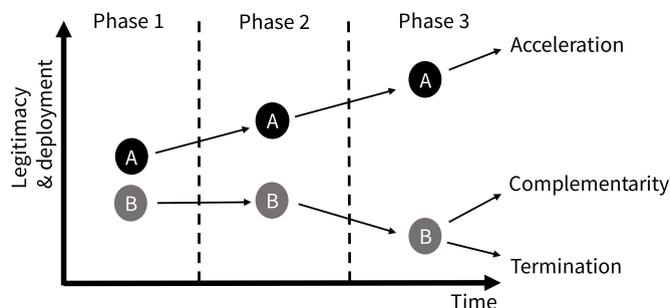


Fig. 9. Relative development of deployment and legitimacy of Technologies A and B. Both are initially regarded worthy of deployment policies and experience technological learning, but Technology A is more dynamic. Later legitimacy diverges as Technology A accelerates deployment, leading to (relatively) decreasing legitimacy and deployment for Technology B and ultimately leading to either policy termination or adaptation to make Technology B complementary to Technology A.

progress is not sufficient for continued or accelerating deployment of promising maturing technologies, because fast progress of adjacent technologies may alter the context alignment, thereby undermining legitimacy and counteracting positive technology-policy feedback. We also showed how support policies and a maturing technology may co-evolve in response to an evolving context, either towards policy termination (e.g., CSP in South Africa) or towards technological adaptation to become complementary to other, more dynamic technologies (e.g., CSP in China). Empirically, we show that PV and wind power indeed contributed to “killing CSP” through negative cross-technology feedback.

These findings add to the existing literature that whereas there are strong intra-technology feedbacks between technological progress and policy (Schmidt and Sewerin, 2017), there are also strong cross-technology feedbacks. In the last decade, wind and PV became so cheap that they not only outcompeted fossil technologies but also other renewables, both in terms of policy attention and investment. CSP deployment is sluggish, not because the technology did not improve, but because other options improved and diffused faster. This suggests that studying policy feedbacks for a single focal technology is insufficient, but researchers need to take into account the policy mix and technology outcomes of all major technologies within the same socio-technical system.

The path-dependency of technologies and policies is well known. Going beyond sequencing (Meckling et al., 2015) and ratcheting-up (Pahle et al., 2018) through strengthening of supporting coalitions another factor for consideration is the dynamics of competing technologies and their supporting coalitions: the relative strength of coalitions is likely important and should be explored in depth in upcoming work. Thus it not only matters that a technology or coalition grows and is protected (or sticky) vis-à-vis incumbent interests, but intra-renewables competition exists too, and understanding the past and near-term future trajectory of one technology requires us to understand the dynamics of adjacent ones. In other words, cross-technology feedback can be another negative feedback that undermining the stickiness of technology specific policies (Sewerin et al., 2023).

Our findings highlight that “technology” is discursively shaped: what it is and represents within each case-study is dynamic and subject to changing interpretations. We show how a technology may alter its purpose and design over time in response to contextual or political changes and thus how policy adaptations may help navigate a shift to a new niche based on updated ideas of *what a technology is, should or could do*, and how these may generate new and diverging technology outcomes. Although CSP still goes by the same name, it has entirely different technological properties and purpose than a decade ago. Especially in China, what is today called “CSP” is rather a storage technology that has little in common with the CSP generation technology deployed previously and in other countries. We showed how especially the PV cost trajectory shifts of cognitive legitimacy of CSP, leading to changes in policy support, which in turn leads to changes in the CSP technology to responding to the adapted requirements from the support instrument.

Our results add to the literature on how policy design produces technology trajectories (Haelg, 2020), by highlighting the importance of narrative dependency. A technological vision supported by underlying modelling of expectations can stir great support and momentum, as the *Desertec* CSP vision did in the early 2000s, among other things inspiring Moroccan CSP policy. But as first projects appeared, the divergence of promises and reality also become clear. As the costs for CSP (e.g. Noor Ouarzazate in Morocco) are today widely seen as excessive, especially in ex-post comparison with PV, CSP is now understood as an expensive technology, causing CSP legitimacy to collapse, in Morocco but also in other countries. Here, negative cross-technology legitimacy feedback amplified resource feedback to terminate subsidies for an “expensive” and now also subjectively redundant technology. Moreover, this label of expensiveness may also affect legitimacy evaluation of future projects for different niches.

This has implications for both scientific analysis and policymaking. Decarbonisation pathway analyses (e.g. IRENA (2021), IEA (2021b)) must clarify what niche a technology should fill, i.e. what kind of CSP the model foresees. Energy system models cannot presently handle such changing technology properties, but rather represent each technology mathematically as an improving (i.e. cheaper, better) but not substantially changing entity – but our findings show that technology may strongly and quickly change its properties while retaining the same name. Both in Morocco and South Africa, CSP is largely evaluated against the visions of 10 years ago – without evaluating the technology considering potential future challenges or opportunities, as now happens in China – potentially terminating CSP-specific support prematurely. Thus, policymakers and analysts need to make transparent different niche applications and also consider emerging opportunities for applying the technology differently than before. Our findings build on empirical insight for CSP, but are relevant for other technologies with slow deployment in search of a niche, such as geothermal, nuclear or biogas power: reformed policies may actively guide and reshape the identity of stagnating technologies through deployment support, thereby helping a technology to solve new problems not initially envisioned.

Our paper has some limitations, most of which can be addressed in future research. First, we did not investigate the political processes leading to policy changes, but only the policy output. This means that we do not know whether or to what extent policy changes or cancellations are also the product of non-energy politics, such as power games within the government or parliament, or of political bargaining. Further research, especially in more democratic countries than in our selection, would be needed to explicate this, and to further strengthen the integration between transition studies and policy sciences. Second, we did not investigate detailed multi-TIS technology legitimacy dynamics. A follow-up study could aim to fully understand these dynamics and the impacts of cross-technology legitimacy feedback across all TIS functions. Third, our findings are limited to the specific case of CSP, and although the theoretical foundation is sound and CSP illustrates it well, we do not know if our proposition holds empirically for further technologies. For example, we would suspect to see that fuel-cell electric vehicles may follow a similar trajectory as CSP in response to negative feedback from cheaper battery-electric vehicles, and from lock-out caused by (e-charger) infrastructure decisions in increasingly many countries; geothermal power, being dispatchable but quite undynamic just like CSP, likely follows a similar pattern as CSP. Finally, we identify patterns of negative cross-technology feedback on a laggard technology and its policy setting in three case studies. Further research may investigate similar interactions among dynamic technologies, and between supply and architectural technologies (Andersen et al., 2023). For example, PV and wind power likely affect each other’s development, and the parallel development of infrastructure options like grid and battery technology will affect the continued trajectory of CSP and other

dispatchable power options. We expect similar cross-technology patterns in zero-carbon mobility technologies or options for industry decarbonisation, leading to policy alteration or cancellation for some technologies and to technological adaptation towards complementarity for others. We thus call for continued empirical research efforts to confirm and refine the idea of cross-technology legitimacy feedback introduced here.

6. Conclusion

Reaching the goal of decarbonising the global economy by the middle of this century will require the deployment of many low carbon technologies that are currently still a small niche. These technologies will not only need to replace currently incumbent emitting technologies, but will also need to fit alongside other widely diffusing low-carbon technologies. We showed how the favourable technology development, cost reductions and diffusion of adjacent technologies feeds back into the politics of other, slower-developing technologies. We propose cross-technology legitimacy feedback as a factor explaining the sluggish deployment and mediocre policy support for such in principle promising, but yet slowly developing technologies and highlight the critical role of relative technology legitimacy. To regain technology legitimacy and ensure continued policy support, innovation systems can harness the potential of innovation for complementarity with more successful technologies and into other niches, just as CSP has evolved into a very different technology today, complementing and supporting the continued deployment of the continuously dynamic PV and wind power technologies.

CRedit authorship contribution statement

Richard Thonig: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Johan Lilliestam:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Funding acquisition, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Richard Thonig reports financial support was provided by IEA SolarPACES secretariat.

Data availability

Data will be made available on request.

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References

- Abbott, A., 1992. From causes to events: notes on narrative positivism. *Sociol. Methods Res.* 20 (4), 428–455.
- ADB, 2022. People's Republic of China: Qinghai Delingha Concentrated Solar Thermal Power Project. Asian Development Bank, Mandaluyong. Online: <http://web.archive.org/save/https://www.adb.org/sites/default/files/project-documents/46058/46058-002-pcr-en.pdf>.
- Alhusen, H., Bannat, T., Bizer, K., Cantner, U., Horstmann, E., Kalthaus, M., Proeger, T., Sternberg, R., Töpfer, S., 2021. A new measurement conception for the 'doing-interacting' mode of innovation. *Res. Policy.* 50 (4), 104214.
- Andersen, A.D., Markard, J., 2020. Multi-technology interaction in socio-technical transitions: how recent dynamics in HVDC technology can inform transition theories. *Technol. Forecast. Soc. Change* 151, 119802.
- Andersen, A.D., Markard, J., Bauknecht, D., Korpås, M., 2023. Architectural change in accelerating transitions: actor preferences, system architectures, and flexibility technologies in the German energy transition. *Energy Res. Soc. Sci.* 97, 102945.
- Ansar, A., Flyvbjerg, B., Budzier, A., Lunn, D., 2014. Should we build more large dams? The actual costs of hydropower megaproject development. *Energy Policy* 69, 43–56.
- Aqachmar, Z., Allouhi, A., Jamil, A., Gagouch, B., Kousksou, T., 2019. Parabolic trough solar thermal power plant Noor I in Morocco. *Energy* 178, 572–584.
- Arrow, K.J., 1962. The economic implications of learning by doing. *Rev. Econ. Stud.* 29 (3), 155–173.
- Baxter, D., Trott, P., Ellwood, P., 2023. Reconceptualising innovation failure. *Res. Policy.* 52 (7), 104811.
- Béland, D., Schlager, E., 2019. Varieties of policy feedback research: looking backward, moving forward. *Policy Studies J.* 47 (2), 184–205.
- Bennett, C.J., Howlett, M., 1992. The lessons of learning: reconciling theories of policy learning and policy change. *Policy Sci.* 25 (3), 275–294.
- Bergek, A., Hansen, T., Hanson, J., Mäkitie, T., Steen, M., 2023. Complexity challenges for transition policy: lessons from coastal shipping in Norway. *Environ. Innov. Soc. Transit.* 46, 100687.
- Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. *Environ. Innov. Soc. Transit.* 16, 51–64.
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Res. Policy.* 37 (3), 407–429.
- Breetz, H., Mildemberger, M., Stokes, L., 2018. The political logics of clean energy transitions. *Bus. Polit.* 20 (04), 492–522.
- Breyer, C., Khalili, S., Bogdanov, D., Ram, M., Oyewo, A., Aghahosseini, A., Gulagi, A., Solomon, A., Keiner, D., Lopez, G., Østergaard, P., Lund, H., Mathiesen, B., Jacobson, M., Victoria, M., Teske, S., Pregger, T., Fthenakis, V., Raugi, M., Holttinen, H., Bardi, U., Hoekstra, A., Sovacool, B., 2022. On the history and future of 100% renewable energy systems research. *IEEe Access.* 10, 78176–78218.

- Brown, T.W., Bischof-Niemz, T., Blok, K., Breyer, C., Lund, H., Mathiesen, B.V., 2018. Response to 'Burden of proof: a comprehensive review of the feasibility of 100% renewable-electricity systems. *Renew. Sustain. Energy Rev.* 92, 834–847.
- Calderbank, S., 2013. Desertec Abandons Sahara solar Power Export Dream. Euractiv. Online: https://web.archive.org/web/20130922055919/https://www.euractiv.com/energy/desertec-abandons-sahara-solar-p-news-5281517%3E%20utm_source=EurActiv%20Newsletter&utm_campaign=58faf148f8-newsletter_daily_update&utm_medium=email&utm_term=0_bab5f0ea4e-58faf148f8-245377373.
- Cantoni, R., Rignall, K., 2019. Kingdom of the Sun: a critical, multiscale analysis of Morocco's solar energy strategy. *Energy Res. Soc. Sci.* 51, 20–31.
- CESE, 2020. Accélérer La Transition énergétique pour Installer Le Maroc dans La Croissance Verte - Auto-Saisine n°45/2020. Conseil Economique, Social et Environnemental, Rabat. Online: <http://web.archive.org/web/20201121120919/https://www.cese.ma/docs/accelerer-la-transition-energetique-pour-installer-le-maroc-dans-la-croissance-verte/>.
- Choukri, K., Naddami, A., Hayani, S., 2017. Renewable energy in emergent countries: lessons from energy transition in Morocco. *Energy Sustain. Soc.* 7 (1), 25.
- Cosin Solar, 2023. 2022 Annual Power Generation Exceeding the Design Value – Supcon Solar Delingha 50MW Molten Salt Tower CSP Plant sees Another Good Year. Cosin Solar. Online: <http://web.archive.org/web/20230213131222/http://www.supconsolar.com/en/news/detail/id/10183.html>.
- CSP Plaza (2017). *China Officially Discloses 20 Concentrated Solar Power demonstration Projects*, Protermosolar. Online: <http://web.archive.org/web/20230215094259/https://helioscsp.com/china-officially-discloses-20-concentrated-solar-power-demonstration-projects/>.
- CSP Plaza, 2021. Summary of the Latest Developments of the First Batch of 20 CSP Demonstration Projects in the Country. CSP Plaza. Online: <http://web.archive.org/save/https://www.csplaza.com/article-19924-1.html>.
- CSP Plaza, 2022. Summary | A list of the Latest Support Policies For Solar Thermal Power Generation. CSP Plaza, Beijing. Online: <https://web.archive.org/web/20220518174735/https://www.csplaza.com/article-254-1.html>.
- CSTA, 2015. China Decides to Organize a Number of CSP Demonstration Projects. China Solar Thermal Alliance, Beijing. Online: <https://web.archive.org/web/20200828073955/http://en.cnste.org/html/csp/2015/1010/167.html>.
- CSTA, 2020. 1.15 yuan/kWh, CGN Delingha and Qinghai Supcon CSP Demonstration Projects Included in the Subsidy List. China Solar Thermal Association, Beijing. Online: <http://web.archive.org/web/20230213130749/http://www.cnste.org/html/jiaodian/2020/0901/6874.html>.
- CSTA, 2022a. Blue Book of China's Concentrating Solar Power Industry 2021. China Solar Thermal Alliance, Beijing. Online: <http://web.archive.org/save/https://www.solarpaces.org/wp-content/uploads/Blue-Book-on-Chinas-CSP-Industry-2021.pdf>.
- CSTA, 2022b. Continuously Operated 262 h! Shouhang Dunhuang 100MW CSP Tower Plant Announced Monthly Generation Data of June. China Solar Thermal Alliance, Beijing. Online: <http://web.archive.org/web/20230213132009/http://en.cnste.org/html/csp/2022/0708/1258.html>.
- Dahmén, E., 1988. Development blocks' in industrial economics. *Scandinavian Econ. History Rev.* 36 (1), 3–14.
- Dehler-Holland, J., Okoh, M., Keles, D., 2021. Assessing technology legitimacy with topic models and sentiment analysis – The case of wind power in Germany. *Technol. Forecast. Soc. Change*, 121354.
- del Río, P., Kiefer, C.P., 2023. Academic research on renewable electricity auctions: taking stock and looking forward. *Energy Policy* 173, 113305.
- DMRE, 2021. Media Statement - Preferred Bidders. Republic of South Africa -Department of Mineral Resources and Energy, Pretoria. Online: <http://web.archive.org/web/20221124155131/https://www.energy.gov.za/files/media/pr/2021/MediaStatement-REIPPPP-BW5-28102021.pdf>.
- DMRE, 2022. Minister Gwede Mantashe Announces 5th Bid Window of Renewable Energy IPP Procurement Programme (REIPPPP Bid Window 5). Republic of South Africa - Department of Mineral Resources and Energy, Pretoria. Online: <http://web.archive.org/web/20230520115009/https://www.gov.za/speeches/minister-gwede-mantashe-announces-5th-bid-window-renewable-energy-ipp-procurement-programme>.
- DoE, 2014a. Energy Announces Bidders For Renewable Energy Independent Power Producers Procurement Programme. Republic of South Africa -Department of Energy, Pretoria. Online: <http://web.archive.org/web/20191005101805/https://www.gov.za/renewable-energy-independent-power-producers-procurement-programme-reippp-financial-close-window-3>.
- DoE, 2014b. Russia and South Africa Sign Agreement On Strategic Partnership in Nuclear Energy. Republic of South Africa -Department of Energy, Pretoria. Online: <http://web.archive.org/web/20230510130030/https://www.gov.za/russia-and-south-africa-sign-agreement-strategic-partnership-nuclear-energy>.
- DoPE, 2016. Minister Lynne Brown Congratulates ESKOM Leadership for Milestone At Medupi. Republic of South Africa - Department of Public Enterprises, Pretoria. Online: http://web.archive.org/web/20170601000000*/https://www.gov.za/speeches/minister-brown-congratulates-eskom-leadership-milestone-medupi-9-sep-2016-0000.
- Duvenhage, D.F., Craig, O.O., Brent, A.C., Stafford, W.H.L., 2018. Future CSP in South Africa – a review of generation mix models, their assumptions, methods, results and implications. *AIP. Conf. Proc.* 2033 (1), 120002.
- Eberhard, A., Gratwick, K., Morella, E., Antmann, P., 2017. Independent power projects in Sub-Saharan Africa: investment trends and policy lessons. *Energy Policy* 108, 390–424.
- Eberhard, A., Kolker, J., Leigland, J., 2014. South Africa's Renewable Energy IPP Procurement Program: Success Factors and Lessons. World Bank Group, Washington, DC. Online: <https://openknowledge.worldbank.org/handle/10986/20039>.
- Eberhard, A., Naude, R., 2016. The South African renewable energy independent power producer procurement programme: a review and lessons learned. *J. Energy Southern Africa* 27, 1–14.
- Eberhard, A., Naude, R., 2017. The South African Renewable Energy IPP Procurement Programme. University of Cape Town, Cape Town. Online: http://web.archive.org/web/20200322185159/https://www.gsb.uct.ac.za/files/EberhardNaude_REIPPPPReview_2017_1_1.pdf.
- Egli, F., 2020. Renewable energy investment risk: an investigation of changes over time and the underlying drivers. *Energy Policy* 140, 111428.
- Eicke, L., Weko, S., 2022. Does green growth foster green policies? Value chain upgrading and feedback mechanisms on renewable energy policies. *Energy Policy* 165, 112948.
- Eljchtimi, A., 2024. Moroccan Solar Plans Hampered by Dispute Over Technology. Reuters. Online: <https://web.archive.org/web/20240229164934/https://www.reuters.com/world/africa/moroccan-solar-plans-hampered-by-dispute-over-technology-2024-02-27/>.
- Ember, 2023. Ember Electricity Data Explorer. Ember Climate, London. Online: <https://web.archive.org/web/20230907091154/https://ember-climate.org/data-catalogue/yearly-electricity-data/>.
- Energy Iceberg, 2020. Would China Finally Solve the Renewable Subsidy Deficit? Energy Iceberg, Hong Kong. Online: <http://web.archive.org/web/20210317094424/https://energyiceberg.com/bond-to-rescue-subsidy-deficit/>.
- Finstad, J., Dahl Andersen, A., 2023. Multi-sector technology diffusion in urgent net-zero transitions: niche splintering in carbon capture technology. *Technol. Forecast. Soc. Change* 194, 122696.
- Frisari, G., Stadelmann, M., 2015. De-risking concentrated solar power in emerging markets: the role of policies and international finance institutions. *Energy Policy* 82, 12–22.
- Garud, R., Schildt, H.A., Lant, T.K., 2014. Entrepreneurial storytelling, future expectations, and the paradox of legitimacy. *Org. Sci.* 25 (5), 1479–1492.
- Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017. Sociotechnical transitions for deep decarbonization. *Science* (1979) 357 (6357), 1242–1244.
- Ginger Phenixa, 2019. Specific Environmental and Social Impact Assessment of the Solar Power Plant project NOOR MIDELT I. Ginger Phenixa, Rabat. https://web.archive.org/web/20210208074537/https://www.masen.ma/sites/default/files/documents_rapport/Masen_NOORM_SESIA_Volume1_Main%20Text.pdf.
- Gosens, J., Gilmanova, A., Lilliestam, J., 2021. Windows of opportunity for catching up in formative clean-tech sectors and the rise of China in concentrated solar power. *Environ. Innov. Soc. Transit.* 39, 86–106.
- Gosens, J., Kaberger, T., Wang, Y.F., 2017. China's next renewable energy revolution: goals and mechanisms in the 13th Five Year Plan for energy. *Energy Sci. Eng.* 5 (3), 141–155.
- Green Giraffe, 2016. Press release: On 15 November 2016, Masen (the Moroccan Agency For Sustainable Energy), Supported By Green Giraffe and Attijari Finance Corp as Joint Financial advisors, Signed a 20-year PPA With ACWA Power for the 170 MW Noor PV 1 program. Green Giraffe. Online: http://web.archive.org/web/20210801000000*/https://green-giraffe.eu/publication/news/masen-selects-acwa-power-170-mw-noor-pv-1-program/.

- Grubb, M., Drummond, P., Poncia, A., McDowall, W., Popp, D., Samadi, S., Penasco, C., Gillingham, K.T., Smulders, S., Glachant, M., Hassall, G., Mizuno, E., Rubin, E. S., Dechezleprêtre, A., Pavan, G., 2021. Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO₂ mitigation. *Environ. Res. Lett.* 16 (4), 043007.
- Gürtler, K., Postpischil, R., Quitzow, R., 2019. The dismantling of renewable energy policies: the cases of Spain and the Czech Republic. *Energy Policy* 133, 110881.
- Haddad, C.R., Nakić, V., Bergek, A., Hellsmark, H., 2022. Transformative innovation policy: a systematic review. *Environ. Innov. Soc. Transit.* 43, 14–40.
- Haegel, N.M., Atwater, H., Barnes, T., Breyer, C., Burrell, A., Chiang, Y.-M., De Wolf, S., Dimmler, B., Feldman, D., Glunz, S., Goldschmidt, J.C., Hochschild, D., Inzunza, R., Kaizuka, I., Kroposki, B., Kurtz, S., Leu, S., Margolis, R., Matsubara, K., Metz, A., Metzger, W.K., Morjaria, M., Niki, S., Nowak, S., Peters, I.M., Philipps, S., Reindl, T., Richter, A., Rose, D., Sakurai, K., Schlatmann, R., Shikano, M., Sinke, W., Sinton, R., Stanbery, B.J., Topic, M., Tumas, W., Ueda, Y., van de Lagemaat, J., Verlinden, P., Vetter, M., Warren, E., Werner, M., Yamaguchi, M., Bett, A.W., 2019. Terawatt-scale photovoltaics: transform global energy. *Science* (1979) 364 (6443), 836–838.
- Haelg, L., 2020. Promoting technological diversity: how renewable energy auction designs influence policy outcomes. *Energy Res. Soc. Sci.* 69, 101636.
- Hedeler, B., Hellsmark, H., Söderholm, P., 2023. Policy mixes and policy feedback: implications for green industrial growth in the Swedish biofuels industry. *Renew. Sustain. Energy Rev.* 173, 113098.
- Helios CSP, 2014. What the Draft IRP Means For Concentrated Solar Power (CSP) in South Africa. Protermosolar, Madrid. Online: <http://web.archive.org/web/20230503084427/https://helioscsp.com/what-the-draft-irp-means-for-concentrated-solar-power-csp-in-south-africa/>.
- IEA, 2021a. An Energy Sector Roadmap to Carbon Neutrality in China. IEA, Paris. Online: <https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china>.
- IEA, 2021b. Net Zero by 2050. IEA, Paris. Online: <https://www.iea.org/reports/net-zero-by-2050>.
- IEA (2022). "Global EV Outlook 2022 Securing supplies for an electric future".
- IRENA, 2021. World Energy Transitions Outlook: 1.5°C Pathway. International Renewable Energy Agency, Abu Dhabi.
- IRENA, 2022. Renewable Power Generation Costs in 2021. IRENA, Abu Dhabi.
- IRP, 2013. Integrated Resource Plan For Electricity (IRP) 2010-2030 Update report 2013. Republic of South Africa - Department of Energy, Pretoria. Online: http://web.archive.org/web/20150419033332/http://www.doe-irp.co.za/content/IRP2010_update.pdf.
- IRP, 2016. Integrated Resource Plan Update Assumptions, Base Case Results and Observations - Revision 1. Republic of South Africa - Department of Energy, Pretoria. Online: <http://web.archive.org/web/20170510060913/https://www.energy.gov.za/irp/2016/draft-irp-2016-assumptions-base-case-and-observations-revision1.pdf>.
- IRP, 2019. Integrated Resource Plan (IRP 2019). Republic of South Africa - Department of Mineral Resources and Energy, Pretoria.
- Kanger, L., Sovacool, B.K., Noorköiv, M., 2020. Six policy intervention points for sustainability transitions: a conceptual framework and a systematic literature review. *Res. Policy.* 49 (7), 104072.
- Kennedy, K.M., Ruggles, T.H., Rinaldi, K., Dowling, J.A., Duan, L., Caldeira, K., Lewis, N.S., 2022. The role of concentrated solar power with thermal energy storage in least-cost highly reliable electricity systems fully powered by variable renewable energy. *Adv. Appl. Energy*, 100091.
- Kern, F., Rogge, K.S., 2018. Harnessing theories of the policy process for analysing the politics of sustainability transitions: a critical survey. *Environ. Innov. Soc. Transit.* 27, 102–117.
- Khumalo, S., 2018. Ramaphosa Tells Putin the Time's Not Right For Nuclear. *News 24*, Cape Town. Online: <https://www.news24.com/Fin24/ramaphosa-tells-putin-the-times-not-right-for-nuclear-20180727-2>.
- Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wiecezorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., Nykvist, B., Pel, B., Raven, R., Rohrachner, H., Sandén, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D., Wells, P., 2019. An agenda for sustainability transitions research: state of the art and future directions. *Environ. Innov. Soc. Transit.* 31, 1–32.
- Larmuth, J., Cuellar, A., 2019. An updated review of South African CSP projects under the renewable energy independent power producer procurement programme (REIPPPP). *AIP. Conf. Proc.* 2126 (1), 040001.
- Lilliestam, J., Bielicki, J., Patt, A., 2012. Comparing carbon capture and storage (CCS) with concentrating solar power (CSP): potentials, costs, risks, and barriers. *Energy Policy* 47, 447–455.
- Lilliestam, J., Labordena, M., Patt, A., Pfenninger, S., 2017. Empirically observed learning rates for concentrating solar power and their responses to regime change. *Nat. Energy* 2, 17094.
- Lilliestam, J., Ollier, L., Labordena, M., Pfenninger, S., Thonig, R., 2021. The near- to mid-term outlook for concentrating solar power: mostly cloudy, chance of sun. *Energy Sources, Part B: Econ., Plann., Policy* 16 (1), 23–41.
- Lilliestam, J., Ollier, L., Pfenninger, S., 2019. The dragon awakens: will China save or conquer concentrating solar power? *AIP. Conf. Proc.* 2126 (1), 130006.
- Lockwood, M., 2022. Policy feedback and institutional context in energy transitions. *Policy Sci.* 55 (3), 487–507.
- Loi no 57-09, 2010. Portant Création De La Société "Moroccan Agency for Solar Energy". *Bulletin Officiel, Rabatt*. Online: https://web.archive.org/web/20170929150421/http://www.sgg.gov.ma/BO/Fr/2010/BO_5822_Fr.pdf.
- Lovegrove, K., Stein, W., 2021. Chapter 1 - Introduction to concentrating solar power technology. In: Lovegrove, K., Stein, W. (Eds.), *Concentrating Solar Power Technology*, 2nd Edition. Woodhead Publishing, pp. 3–17.
- Lu, X., Chen, S., Nielsen, C.P., Zhang, C., Li, J., Xu, H., Wu, Y., Wang, S., Song, F., Wei, C., He, K., McElroy, M.B., Hao, J., 2021. Combined solar power and storage as cost-competitive and grid-compatible supply for China's future carbon-neutral electricity system. *Proc. Nat. Acad. Sci.* 118 (42) e2103471118.
- Malhotra, A., Zhang, H., Beuse, M., Schmidt, T., 2021. How do new use environments influence a technology's knowledge trajectory? A patent citation network analysis of lithium-ion battery technology. *Res. Policy.* 50 (9), 104318.
- Markard, J., Bento, N., Kittner, N., Nuñez-Jimenez, A., 2020. Destined for decline? Examining nuclear energy from a technological innovation systems perspective. *Energy Res. Soc. Sci.* 67, 101512.
- Markard, J., Hoffmann, V.H., 2016. Analysis of complementarities: framework and examples from the energy transition. *Technol. Forecast. Soc. Change* 111, 63–75.
- Markard, J., Wirth, S., Truffer, B., 2016. Institutional dynamics and technology legitimacy – A framework and a case study on biogas technology. *Res. Policy.* 45 (1), 330–344.
- Masen, 2015. Call For Expression of Interest For First Phase of Noor Midelt Complex Development Project (s), in the Framework of the Moroccan solar plan, Noor. Moroccan Agency for Solar Energy, Rabatt. Online: http://web.archive.org/web/20210210125601/http://www.energiextremadura.org/www/wp-content/uploads/2016/01/Masen-Noor-Midelt-Phase-I-CfEoI-2015-12-31_VF.pdf.
- Meckling, J., Kelsey, N., Biber, E., Zysman, J., 2015. Winning coalitions for climate policy. *Science* (1979) 349 (6253), 1170–1171.
- Mehos, M., H. Price, R. Cable, D. Kearney, B. Kelly, G. Kolb and F. Morse (2020). *Concentrating Solar Power Best Practices Study*. United States.
- Melliger, M., Lilliestam, J., 2021. Effects of coordinating support policy changes on renewable power investor choices in Europe. *Energy Policy* 148, 111993.
- Moyo, A., 2016. Eskom Shelves R50bn Renewable Energy Deal. *iT Web, Johannesburg*. Online: <http://web.archive.org/web/20210918070955/https://www.itweb.co.za/content/R8OKdWMDnaXvbnzQ>.
- NDRC, 2021a. 14th Five-year Plan For Renewable Energy Development. People's Republic of China - National Development and Reform Commission, Beijing. Online: <http://web.archive.org/save/https://chinaenergyportal.org/en/14th-five-year-plan-for-renewable-energy-development/>.
- NDRC, 2021b. Circular of the National Development and Reform Commission On Matters Concerning the 2021 New Energy On-grid Tariff Policy. People's Republic of China - National Development and Reform Commission, Beijing. Online: http://web.archive.org/web/20230213102248/http://www.gov.cn/zhengce/zhengceku/2021-06/11/content_5617297.htm.
- NEA, 2016. Construction Notice of Solar Thermal Power Demonstration Project. People's Republic of China - National Energy Administration, Beijing. Online: http://web.archive.org/web/20170501055017/http://zfxgk.nea.gov.cn/auto87/201609/t20160914_2298.htm.
- NEA, 2022a. Guiding Opinions on Energy Work in 2022 [2022年能源工作指导意见]. People's Republic of China - National Energy Administration, Beijing. Online: http://web.archive.org/web/20230215141841/http://www.gov.cn/zhengce/zhengceku/2022-03/29/content_5682278.htm.

- NEA, 2022b. In the "subsidy-free era", Xinjiang raised the On-Grid Electricity Price of New Energy to Promote Low-Carbon Energy Development. People's Republic of China - National Energy Administration, Beijing. Online: http://web.archive.org/save/http://www.nea.gov.cn/2022-04/15/c_1310559938.htm.
- Nemet, G.F., 2019. *How Solar Energy Became Cheap: A Model For Low-Carbon Innovation*. Routledge, London.
- Nemet, G.F., Zipperer, V., Kraus, M., 2018. The valley of death, the technology pork barrel, and public support for large demonstration projects. *Energy Policy* 119, 154–167.
- NERSA, 2021. *Concurrence With the Ministerial Determination On the Procurement of 404 MW New Generation Capacity from Battery Energy Storage Systems and Solar PV*. Pretoria. National Energy Regulator of South Africa. Online: <http://web.archive.org/web/20220316124727/https://www.nersa.org.za/wp-content/uploads/2022/03/Decision-and-RFD-404MW-Final.pdf>.
- Pahle, M., Burtraw, D., Flachsland, C., Kelsey, N., Biber, E., Meckling, J., Edenhofer, O., Zysman, J., 2018. Sequencing to ratchet up climate policy stringency. *Nat. Clim. Chang.* 8 (October), 861–867.
- Pierson, P., 1993. When Effect Becomes Cause: policy Feedback and Political Change. *World Polit.* 45 (4), 595–628.
- Protermosolar, 2019. *China Finish Feasibility Study of Another 3 GW CSP (Concentrated Solar Power) Projects*. Protermosolar, Madrid. Online: <https://web.archive.org/web/2021002212106/http://helioscsp.com/china-finish-feasibility-study-of-another-3-gw-csp-concentrated-solar-power-projects/>.
- Quitowz, R., 2015. Dynamics of a policy-driven market: the co-evolution of technological innovation systems for solar photovoltaics in China and Germany. *Environ. Innov. Soc. Transit.* 17, 126–148.
- Rathi, A., 2022. Why South Africa is in the dark, again. *Foreign Policy*. Foreign Policy, Washington, D.C.
- Relancio, J., Cuellar, A., Walker, G., Ettmayr, C., 2016. South African CSP projects under the REIPPP programme – Requirements, challenges and opportunities. *AIP. Conf. Proc.* 1734 (1), 110002.
- REN21, 2023. *Renewables 2023 Global Status Report Collection*. Renewable Energy Policy Network for the 21st Century, Paris.
- Resch, G., Schöniger, F., Kleinschmitt, C., Franke, K., Thonig, R., Lilliestam, J., 2022. Deep decarbonization of the European power sector calls for dispatchable CSP. *AIP. Conf. Proc.* 2445 (1), 050006.
- Reuters Events, 2019. Noor Midelt winner Optimizes CSP trough, Storage to Hit Record Price. Reuters, Toronto. Online: <http://web.archive.org/web/20201201030713/https://www.reuters.com/renewables/csp-today/noor-midelt-winner-optimizes-csp-trough-storage-hit-record-price>.
- Roelf, W., 2017. South African court Declares Nuclear Plan With Russia unlawful. Reuters, Toronto. Online: <http://web.archive.org/web/20221227132421/https://www.reuters.com/article/us-safrica-nuclear-court-idUSKBN17S25R>.
- Rosenbloom, D., Meadowcroft, J., Cashore, B., 2019. Stability and climate policy? Harnessing insights on path dependence, policy feedback, and transition pathways. *Energy Res. Soc. Sci.* 50, 168–178.
- RSA, 2005. *National Energy Regulator Act, 2004*. Gazette of the Republic of South Africa - Staatskoerant, Cape Town. Online: <http://web.archive.org/web/20220511090751/https://www.gov.za/documents/national-energy-regulator-act>.
- RSA, 2006. *Electricity Regulation Act, 2006*. Gazette of the Republic of South Africa - Staatskoerant, Cape Town. Online: <http://web.archive.org/save/https://www.gov.za/documents/electricity-regulation-act>.
- RSA, 2011. *Electricity Regulation Act (4/2006): Electricity Regulations On New Generation Capacity*. Gazette of the Republic of South Africa - Staatskoerant, Cape Town. Online: <http://web.archive.org/web/20170218181642/https://www.energy.gov.za/files/policies/electricity%20regulations%20on%20new%20generation%20capacity%201-34262%204-5.pdf>.
- RSA, 2012. *Electricity Regulation Act (4/2006): IPP Procurement Programme 2012*. Republic of South Africa - Staatskoerant, p. 36005. Online: <http://web.archive.org/save/https://gazzettes.africa/akn/za/officialGazette/government-gazette/2012-12-19/36005/eng@2012-12-19>.
- RSA, 2020. *Determination Under Section 34(1) of the Electricity Regulation Act, 2006 (Act No. 4 of 2006)*. Gazette of the Republic of South Africa - Staatskoerant, Cape Town. Online: <http://web.archive.org/web/20220813032812/https://sawea.org.za/wp-content/uploads/2020/09/mineral-resources-and-energy-department-of-mineraalbronne-en-energie-departement-van-1015-electricity-regulations-act-4-2006-determination-under-section-34-1-of-t.pdf>.
- Sabatier, P.A., 1988. An advocacy coalition framework of policy change and the role of policy-oriented learning therein. *Policy Sci.* 21 (2), 129–168.
- Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. *Res. Policy.* 40 (3), 403–414.
- SBP, 2021. *Press release: EuroTrough Helped Cut Ramp-Up Time of China's 100 MW Urat CSP*. SBP Sonne GmGH, Stuttgart. Online: <https://web.archive.org/web/20210316090916/https://www.solarpaces.org/eurotrough-cut-ramp-up-in-china-100-mw-urat-csp%E2%80%A8>.
- Schmid, N., Sewerin, S., Schmidt, T.S., 2020. Explaining advocacy coalition change with policy feedback. *Policy Stud. J.* 48 (4), 1109–1134.
- Schmidt, T.S., Sewerin, S., 2017. Technology as a driver of climate and energy politics. *Nat. Energy* 2, 17084.
- Schmitt, T.M., 2018. Why did Desertec fail? An interim analysis of a large-scale renewable energy infrastructure project from a Social Studies of Technology perspective. *Local. Environ.* 23 (7), 747–776.
- Schöniger, F., Thonig, R., Resch, G., Lilliestam, J., 2021. Making the sun shine at night: comparing the cost of dispatchable concentrating solar power and photovoltaics with storage. *Energy Sources, Part B: Econ., Plann., Policy* 16 (1), 55–74.
- Sewerin, S., Béland, D., Cashore, B., 2020. Designing policy for the long term: agency, policy feedback and policy change. *Policy Sci.* 53 (2), 243–252.
- Sewerin, S., Fesenfeld, L., Schmidt, T., 2023. The role of policy design continuation and ratcheting-up of policy ambition. *Policy Soc.* 42 (4), 478–492.
- Sharpe, S., Lenton, T.M., 2021. Upward-scaling tipping cascades to meet climate goals: plausible grounds for hope. *Clim. Policy.* 21 (4), 421–433.
- Silinga, C., Gauché, P., Rudman, J., Cebecauer, T., 2015. The South African REIPPP two-tier CSP tariff: implications for a proposed hybrid CSP peaking system. *Energy Procedia* 69, 1431–1440.
- Simoens, M.C., Leipold, S., Fuenfschilling, L., 2022. Locked in unsustainability: understanding lock-ins and their interactions using the case of food packaging. *Environ. Innov. Soc. Transit.* 45, 14–29.
- Sinsel, S.R., Markard, J., Hoffmann, V.H., 2020. How deployment policies affect innovation in complementary technologies—evidence from the German energy transition. *Technol. Forecast. Soc. Change* 161, 120274.
- SolarPaces. (2018). "China to extend deadline for late CSP Demos – but add penalty." from <https://www.solarpaces.org/china-to-extend-deadline-for-late-csp-demos-but-add-penalty/>.
- Song, D., Jia, B., Jiao, H., 2022. Review of Renewable Energy Subsidy System in China. *Energies*. (Basel) 15. <https://doi.org/10.3390/en15197429>. DOI: 10.3390/en15197429.
- Sovacool, B.K., Baum, C.M., Low, S., Roberts, C., Steinhauser, J., 2022. Climate policy for a net-zero future: ten recommendations for Direct Air Capture. *Environ. Res. Lett.* 17 (7), 074014.
- State Council, 2015. *Circular of the State Council on Printing and Distributing "Made in China 2025"*. People's Republic of China - State Council, Beijing. Online: http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm.
- Strauch, Y., 2020. Beyond the low-carbon niche: global tipping points in the rise of wind, solar, and electric vehicles to regime scale systems. *Energy Res. Soc. Sci.* 62, 101364.
- Suchman, M.C., 1995. *Managing Legitimacy: strategic and Institutional Approaches*. *Acad. Manag. Rev.* 20 (3), 571–610.
- Swilling, M., 2019. Wake up, Everyone: ANC NEC's Energy Statement is a Real New Dawn for South Africa. *Daily Maverick*, Cape Town. Online: <http://web.archive.org/web/20191220235737/https://www.dailymaverick.co.za/opinionista/2019-10-04-wake-up-everyone-anc-necs-energy-statement-is-a-real-new-dawn-for-south-africa/>.
- Tardy, T., Lu, Y., 2014. Noor 1 - World's largest CSP plant. *Project Finance Int.*
- Thompson, M., Ellis, R., Wildavsky, A., 1990. *Cultural Theory*. Westview Press, Boulder, Colorado.
- Thonig, R., Del Río, P., Kiefer, C., Lázaro Touza, L., Escibano, G., Lechón, Y., Späth, L., Wolf, I., Lilliestam, J., 2021. Does ideology influence the ambition level of climate and renewable energy policy? Insights from four European countries. *Energy Sources, Part B: Econ., Plann., Policy* 1–19.
- Thonig, R., Gilmanova, A., Lilliestam, J., 2023. *CSP.guru 2023-07-01 [Data Set]*. Zenodo. <https://doi.org/10.5281/zenodo.8191855>.
- Thonig, R., Gilmanova, A., Zhan, J., Lilliestam, J., 2022. Chinese CSP for the world? *AIP. Conf. Proc.* 2445 (1), 050007.

- Ting, M.B., Byrne, R., 2020. Eskom and the rise of renewables: regime-resistance, crisis and the strategy of incumbency in South Africa's electricity system. *Energy Res. Soc. Sci.* 60, 101333.
- Trencher, G., Rinscheid, A., Duygan, M., Truong, N., Asuka, J., 2020. Revisiting carbon lock-in in energy systems: explaining the perpetuation of coal power in Japan. *Energy Res. Soc. Sci.* 69, 101770.
- Trieb, F., Schillings, C., O'Sullivan, M., Pregger, T., Hoyer-Klick, C., 2009. Global Potential of Concentrating Solar Power. *SolarPACES*, Bonn, p. 2009.
- Trieb, F., Schillings, C., Pregger, T., O'Sullivan, M., 2012. Solar electricity imports from the Middle East and North Africa to Europe. *Energy Policy* 42, 341–353.
- Tröndle, T., Lilliestam, J., Marelli, S., Pfenninger, S., 2020. Trade-offs between geographic scale, cost, and system design for fully renewable electricity in Europe. *Joule*.
- Turnheim, B., Sovacool, B.K., 2020. Exploring the role of failure in socio-technical transitions research. *Environ. Innov. Soc. Transit.* 37, 267–289.
- Unruh, G.C., 2002. Escaping carbon lock-in. *Energy Policy* 30 (4), 317–325.
- Verbong, G., Geels, F.W., Raven, R., 2008. Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970–2006): hype-cycles, closed networks and technology-focused learning. *Technol. Anal. Strateg. Manage* 20 (5), 555–573.
- Wang, J., Zhong, H., Ma, Z., Xia, Q., Kang, C., 2017. Review and prospect of integrated demand response in the multi-energy system. *Appl. Energy* 202, 772–782.
- Wang, L., Wang, M., 2022. China's Curtailments go Up As Renewables Growth Explodes. *Xinhua News Agency*, Beijing. https://web.archive.org/web/20230907083710/http://www.jjckb.cn/2022-06/06/c_1310614914.htm.
- Wiatros-Motyka, M., 2023. *Global Electricity Review 2023*. Ember, London.
- Winkler, H., 2018. Key Questions the Zondo Inquiry Needs to Pose About the Nuclear Deal. *The Conversation*, Melbourne. Online: <http://web.archive.org/web/20221201070346/https://theconversation.com/key-questions-the-zondo-inquiry-needs-to-pose-about-the-nuclear-deal-102139>.
- Worldbank, 2011. South Africa - ESKOM Renewables Support Project. Worldbank, Washington. Online: <http://web.archive.org/save/https://pubdocs.worldbank.org/en/305531531492673253/1780-XCTFZA069A-South-Africa-Project-Document.pdf>.
- Worldbank, 2017. Joint AfDB-WB Submission Document: Morocco: Noor-Midelt Phase 1 Concentrated Solar Power Project. Worldbank, Washington. Online: <http://web.archive.org/web/20230601075815/https://pubdocs.worldbank.org/en/930461531492489703/1807-XCTFMB107A-Middle-East-and-North-Africa-region-project-document.pdf>.