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Too good to be true? How time-inconsistent renewable energy policies can deter investments

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Discussion
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Too Good to Be True? How Time-Inconsistent Renewable Energy Policies Can Deter Investments*

Nils May[†], Olga Chiappinelli[‡]

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Abstract

The transition towards low-carbon economies requires massive investments into renewable energies, which are commonly supported through regulatory frameworks. Yet, governments can have incentives – and the ability – to deviate from previously-announced support once those investments have been made, which can deter investments. We analyze a renewable energy regulation game, apply a model of time-inconsistency to renewable energy policy and derive under what conditions governments have incentives to deviate from their commitments. We analyze the effects of various support policies and deployment targets and explain why Spain conducted retrospective changes in the period 2010-2013 whereas Germany stuck to its commitments.

Key words: Time-Inconsistency; Regulation; Targets; Renewable Energy Policy; Investments

JEL classification: Q42, Q55, O38, C73

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1 Introduction

In 2016, global investments into renewables-based power capacity outpaced investments into coal and gas power plants, amounting to €297 billion (IEA, 2017). Investment needs remain high over the next decades, supporting countries' transitions to not just low-carbon electricity but also other energy sectors. The vast majority of renewable energy projects are facilitated through supportive regulatory frameworks and policies. These policies offset the usually not-internalized negative externalities of thermal power plants and support the learning of technologies (Edenhofer et al., 2013).

Governments support renewable energy investments by promising investors certain policy frameworks and remuneration levels. Time-inconsistency can arise as regulators follow a multi-objective agenda: They pursue long-term decarbonization trajectories, yet these may conflict with short term distributional concerns regarding the costs of energy (Chiappinelli and Neuhoff, 2017). Moreover, in addition to the desire to do so, regulators can have the ability to deviate from previously-announced support levels since renewable energy investments are irreversible and operate at very low marginal costs: Regulators interested in renewable energy announce support levels to be paid via levies on electricity, based on which investors respond by investing into new capacity. However, regulators then possibly deviate, not paying out the promised support, benefiting from both the now-existing renewable energy capacity and the low costs of electricity. Firms anticipate this opportunistic behavior and do not invest in the first place. However, when the game is repeated, there is scope for compliance depending on policies and technology parameters.

The monetary policy literature first applied time-inconsistency concepts to inflation and economic growth. In their ground-breaking article, Kydland and Prescott (1977) analyze unemployment and inflation and lay out the problem that rational agents optimizing at different points in time adjust their behavior simply due to the different timing, leading to sub-optimal outcomes when agents are rational. Barro and Gordon (1983) underpin the argument that rules for government behavior can have favorable outcomes rather than the discretion to adjust policies when optimal.

Subsequently, the concept has been used to analyze broader climate policies. Helm et al. (2003) demonstrate that emission pricing faces similar problems since agents foresee that incentives for emission reductions that are optimal *ex-ante* become suboptimal *ex-post*, thus diminishing their credibility in the first place. This is extended for different cases, e.g. where governments and firms are uncertain about future governments' preferences, inducing arguments for research grants (Ulph and Ulph, 2013). Brunner et al. (2012) discuss solutions to the commitment problem with a focus on delegation to an independent climate agency, long-term planning via targets and securitization through legal rights. In this context, they mention feed-in tariffs for renewable energies as favorable example and dismiss the retrospective changes that Spain had just initiated as "unlikely to affect investors property" (p.16), which has since turned out to be incorrect. Remuneration levels were cut by around 25 percent on average (Comisión Nacional de los Mercados y la Competencia, 2014, 2015).

Renewable energy policy has some common features with general environmental regulation: Demand for renewable energy is driven and affected by government regulations. Due to their high initial capital intensity and low marginal

costs, investments into wind and solar power are potentially exposed to time-inconsistency issues as once investments are made, operators will usually operate the assets independent of remuneration. Consequently, governments might face incentives to deviate because existing installations will run in any case.

We contribute to the literature by scrutinizing time-inconsistency problems of renewable energy policies in detail. Building on the analysis of time-inconsistency of environmental regulation by Chiappinelli and Neuhoff (2017), we show that renewable energy policies can be affected by time-inconsistency and consider different policy regimes and how they affect regulatory compliance. As renewable energy support is usually not paid out as capacity support, but rather over the projects' lifetimes as payments for output, we model the interaction between firms and the government as a dynamic game where the effects of past periods' support commitments and investments last into the present.

We analyze commitment devices in the field of renewable energy. While Borghesi (2011) argues that renewable energy targets, like the European 2020 renewable energy targets can incentivize commitment, we show that targets only do so under certain conditions. Habermacher and Lehmann (2017) analyze more generally how uncertainty about environmental benefits leads to changing optimal support levels over time, but do not focus on the classical commitment problem where the optimal regulatory support differs over time even in the absence of new information.

Our analysis can explain why some countries deviate from their announced renewable energy support policies while others do not. For example, Spain, then a global frontrunner in renewable energies, cut its renewable energy support over the 2010 to 2013 period, while Germany, another frontrunner, did not.

The paper is structured as follows: Section 2 describes the dynamic regulatory game. Section 3 characterizes optimal regulatory and firm behavior. We discuss the effects of various renewable energy policies and targets in section 4. Next, in section 5, we proceed to apply the model to the situations facing Spain and Germany around 2012 to derive reasons for their differing behavior. The paper ends with a conclusion.

2 Setup of the regulation game

Regulatory support for renewable energies can be modeled as a game where the regulator announces and sets support levels, while firms form expectations about the anticipated support levels and choose to invest or not. A dynamic regulatory game is a useful model of renewable energies support policies for the following reasons: First, investments into renewable energies are capital intensive up-front, which implies that expectations about lifetime earnings formed at the investment stage define capital costs and, thus, the required support level (see, among others, Couture et al., 2010; Haas et al., 2011; May, 2017). Due to the dependence of investments on support policies, investors emphasize the importance of stable regulation without unexpected changes (Lüthi and Wüstenhagen, 2012). Only a small fraction of the costs is incurred after the investment stage, such that installations will operate (almost) independent of actual revenues. This matters because, secondly, renewable support is typically paid out throughout the lifetime of the assets as support per output to incentivize efficient project planning and management. Consequently, over the

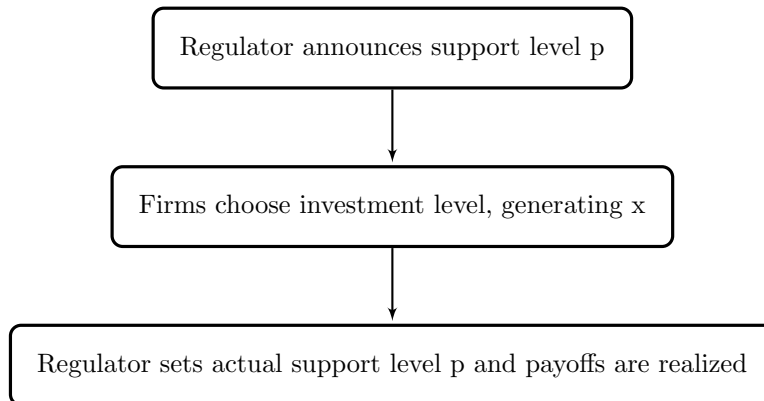


Figure 1: Timing of the period game, which is repeated indefinitely

lifetime of the assets, there is ample time for regulators to behave strategically and to deviate of their initial support commitments because the assets will continue generating power regardless.

The government acts as Nash leader, such that it announces a renewable energy regime and support level that a representative firm, as Nash follower, can observe and take into account for its investment decision. The firms invest into renewable energy depending on the remuneration they expect.

The game modifies the more general setup introduced by Chiappinelli and Neuhoff (2017) modified to take into account dynamic aspects of the interaction between the government and the firms and, thus, depicting the renewable energy setting in more detail. Figure 1 visualizes the general setup. First, the government announces its support for renewable energy. The remuneration is financed as a levy on the electricity price, to be paid by all electricity consumers, thus decreasing the demand for electricity, as is implemented in most European countries (Eclareon, 2017). Second, the firms choose to invest into renewable energy capacity, generating renewable energy. Third, the government observes the firms' investment decisions and sets the actual remuneration level. This reflects that regulators can, if the policy design allows them to, alter the support level after project completion, effectively changing the remuneration over the entire lifetime of the project.

To reflect that renewable energy support is almost universally paid out per unit of output, rather than installed capacity, the model is dynamic and actions directly affect future periods. Support promised in period t lasts into the next period $t + 1$ and investments undertaken in t still reduce emissions in $t + 1$, after which they are assumed to cease operating.

We adopt a linear direct demand function Q_t where electricity prices increase with renewable energy support: Without support, demand is equal to a and decreases by b for every Euro of support per megawatt hour (MWh). Support for renewable energies p is promised for two periods,¹ such that both the past period's promised support p_{t-1} and the present support p_t influence demand in

¹While this can easily be increased to longer support horizons, it does not alter the nature of the results; such that we stick to two periods for notional simplicity.

the present.

$$Q_t = a - bp_{t-1} - bp_t \quad (1)$$

In every period, the government optimizes welfare W_t by setting the renewable energy levy p_t . The regulator represents the interests of electricity customers and, thus, cares about consumer surplus, comparable to the model setup in Salant and Woroch (1992), but also cares about environmental pollution, as in Chiappinelli and Neuhoff (2017). As shown in equation (2), per-period welfare depends on the consumer surplus from the consumption of electricity (first term) and the environmental damage caused by the production of non-renewable electricity (second term).² Damage depends on emissions from covering the demand and are reduced by generation from renewable energies. These renewable energies are the sum of generation across all firms j , $\sum_{j=1}^J x_{j_t}$ and $\sum_{j=1}^J x_{j_{t-1}}$,³ again reflecting that previous investments impact later periods. The sum is multiplied with a pollution parameter e , indicating how polluting the non-renewable power supply is.⁴

$$W_t = \int_{p_t}^{p'_t} Q(z) dz - e(Q_t - \sum_{j=1}^J x_{j_t} - \sum_{j=1}^J x_{j_{t-1}}) \quad (2)$$

The maximum total support, at which electricity demand drops to zero, is given by $\frac{a}{b}$. Consequently, the maximum level for p_t is $p'_t = \frac{a}{b} - p_{t-1}$.

In the long-run, welfare is the sum of future welfare, discounted by the discount factor $\delta \in [0, 1]$.

$$W = \sum_{s=t}^{\infty} \delta^{s-t} \left[\int_{p_s}^{p'_s} Q(z) dz - e(Q_s - \sum_{j=1}^J x_{j_s} - \sum_{j=1}^J x_{j_{s-1}}) \right] \quad (3)$$

The firms are identical competitive price-takers, representing the investment behavior of renewable energy investors and covering all demand. Every individual firm's renewable generation x_{i_t} is very small compared to the sum of all firms' generation $\sum_{j=1}^J x_{j_t}$. For simplicity, the convex cost function $c(x_{i_t})$ is assumed to be quadratic in investments, depending on some factor $\alpha > 0$, as shown in equation (4). Costs occur up-front and increase with deployment because project developers might only have capacities to implement a limited number of projects at a time and because suitable sites are scarce. Marginal operational costs are zero.

$$c(x_{i_t}) = \frac{\alpha}{2} x_{i_t}^2 \quad (4)$$

²We are interpreting the alternative to investments into renewable energy as running existing thermal plants, e.g. coal and gas power plants. The avoided costs of running these, the so-called merit-order effects (Ketterer, 2014), implicitly dampen the costs for renewable energy support. In the numerical application in section 5, we subtract these costs from the renewables' support costs.

³Precisely, x stands for renewable energy generation, so when discussing "investments", we refer to "the investments necessary to generate x ".

⁴Not all non-renewable electricity is equal. With increasing renewable energy shares, thermal power plants with higher marginal costs, e.g. gas power plants in most of Europe, might be replaced first, while other plants are replaced later. We abstract from this differentiation and assume one single pollution parameter.

Each firm's short-run profits π_{i_t} are influenced by the firm's present and past renewable energy investments x_{i_t} and $x_{i_{t-1}}$ and the support per unit of output. The overall support payments divided by the overall new generation from renewables, $\frac{p_t Q_t}{\sum_{j=1}^J x_{j_t}}$, represent the support per unit of output. Stated differently, the ratio $\frac{x_{i_t}}{\sum_{j=1}^J x_{j_t}} p_t Q_t$ indicates how much of the overall support for renewable energies for new generation in period t , $p_t Q_t$, is generated by firm i .⁵

$$\pi_{i_t} = \frac{x_{i_t}}{\sum_{j=1}^J x_{j_t}} p_t Q_t + \frac{x_{i_{t-1}}}{\sum_{j=1}^J x_{j_{t-1}}} p_{t-1} Q_{t-1} - c_t \quad (5)$$

In the long-run, firms' profits are the sum of all future profits, discounted by the discount factor δ .

$$\pi_i = \sum_{s=t}^{\infty} \delta^{s-t} \left[\frac{x_{i_s}}{\sum_{j=1}^J x_{j_s}} p_s Q_s + \frac{x_{i_{s-1}}}{\sum_{j=1}^J x_{j_{s-1}}} p_{s-1} Q_{s-1} - c_{i_s} \right] \quad (6)$$

3 Regulatory optima

The government maximizes welfare by setting the support level, while the firms maximize profits by choosing investment levels. In the commitment benchmark, the government has to set exactly the level it has previously announced, whereas in the absence of commitment, it has the ability to deviate. In the absence of renewable energy investments, electricity demand is covered by conventional technologies, leading to proportional environmental damage.⁶

3.1 Commitment benchmark

When the government can commit to a particular support level p_t , it can take the firms' reaction function $\sum_{j=1}^J x_{j_t}(p_t)$ into account for its optimization of welfare W . Accordingly, we solve the game by backward induction, starting with the firms' reaction function. When optimizing, any firm's production is very small compared to overall production such that it takes the sum of production as constant. This implies that any one firm's action does not alter the support per output, whereas all firms' collective investments may well change the support per output.

Deriving any firm's profit function yields that its marginal costs, αx_{i_t} , must in the optimum equal its marginal revenues, $\frac{p_t(Q_t + \delta Q_{t+1})}{\sum_{j=1}^J x_{j_t}}$, which are composed of the revenues in the investment period and in the discounted subsequent

⁵To ensure that levy payments by electricity consumers and pay-offs for renewable energy output match exactly, independent of demand fluctuations, balancing accounts facilitate this inter-temporal exchange, cp. for example the German "renewable energy accounts" (Bundestag, 2016). For simplicity and as the management of these balancing accounts is not our focus, we abstract from them and assume that levy payments and payouts match exactly in every period.

⁶We assume that in the absence of any renewable investments, the government will always set a support level of zero, i.e. curbing demand is not an end in itself. Appendix 7.1 spells out this condition.

period. The optimal investments are thus:

$$x_{i_t}^* = \frac{p_t(Q_t + \delta Q_{t+1})}{\alpha \sum_{j=1}^J x_{j_t}} \quad (7)$$

Therefore, the sum of renewable energy generation from new investments is:

$$\sum_{j=1}^J x_{j_t}^* = \frac{p_t(Q_t + \delta Q_{t+1})}{\alpha} \quad (8)$$

Consequently, the regulator takes the firms' investment decisions into account when setting the optimal support level p_s which maximizes welfare:

$$W = \sum_{s=t}^{\infty} \delta^{s-t} \left[\int_{p_s}^{p'_s} Q(z) dz - e(Q_s - \frac{p_s(Q_s + \delta Q_{s+1})}{\alpha} - \frac{p_{s-1}(Q_{s-1} + \delta Q_s)}{\alpha}) \right] \quad (9)$$

In the optimum, the regulator sets the support level in every period such that on the margin, the additional costs of an increase in the levy in terms of reduced consumer surplus equal the environmental benefits of the increase of the levy. The regulator is able to do this under commitment as it knows the firms' reaction functions and possesses perfect foresight. Consequently, in this simple setup without new information during the game, the regulator will optimally set the same levy in every period, $p_{t-1} = p_t = p_{t+1}$. Any deviation would decrease welfare. When increasing the levy from this optimal levy, the costs of a higher levy would not be worth the resulting environmental benefits. When decreasing the levy, welfare would be lower due to the forsaken environmental benefits.⁷ Imposing the steady state yields:

$$p^* = \frac{a\alpha - bec - ae - ae\delta}{b(2c + 2c\delta - 3e - 8e\delta - 4e\delta^2)}(1 + \delta) \quad (10)$$

Overall, investments are:

$$\sum_{j=1}^J x_j^* = \frac{p^*a - 2bp^*}{\alpha}(1 + \delta) \quad (11)$$

Every firm invests:

$$x_i^* = \frac{p^*a - 2bp^*}{\alpha \sum_{j=1}^J}(1 + \delta) \quad (12)$$

⁷In our setup, a potentially optimal alternative to the steady state exists: Consumer surplus is decreased by the sum of the levy of the current and the previous period. Thus, the levy does not actually have to be equal in every individual period in order to set the marginal costs of an increase of the levy equal to the marginal benefits of an increase of the levy; it suffices that the total levy per-period payments are the same. Thus, the regulator could constantly switch between a high levy in one period and a low levy in the next period, such that the total per-period levy payments are the same in all periods. However, this decreases welfare due to the convexity of costs in combination with linear demand and linear environmental damages. Besides, this seems unrealistic, as real-options theory indicates that potential investors would delay their investments until levies are high, see e.g. Ritzenhofen and Spinler (2016).

3.2 Dynamic optimization: no commitment case

Without commitment, the regulator deviates from the announced support level if that is optimal. Whether or not it is optimal depends on the strategies the players are following: Under open-loop strategies, they only consider the current period's pay-offs, while under trigger strategies, past actions impact future actions. We explore how far the commitment outcome can be attained under these strategies and what factors attainment relies on.

3.2.1 Open loop strategies

When the government cannot commit, it can observe the firms' investment decisions and choose to set the remuneration level to the level that optimizes welfare, independent of its initial announcement. The government optimizes, taking the renewable energy output as exogenously given.

$$\frac{\partial W}{\partial p_t} = \sum_{s=t}^{\infty} \delta^{s-t} \left[\frac{\partial}{\partial p_t} \int_{p_s}^{p'_s} Q(z) dz - e \frac{\partial Q_s}{\partial p_t} \right] \quad (13)$$

Any positive remuneration level curbs demand, which reduces consumer surplus. The only benefits are the avoided emissions due to the lower demand. However, we assumed that the regulator will not set a levy only in order to curb demand, see appendix 7.1. Thus, the government sets the support level to zero. The firms anticipate this and optimally choose not to invest – a classical expropriation argument (see e.g. Williamson (1975)).

3.2.2 Grim trigger strategies

With trigger strategies, the players are able to observe the other's past behavior and react. A grim trigger means that once the a play deviates, she is punished forever. In our setup, since only the regulator can deviate owing to the timing of output-based support payments, only the firms can punish by not making further investments after the regulator has deviated from its previously-announced support. In order to sustain a subgame perfect Nash equilibrium, a deviation may not be profitable for the regulator at any time. For a detailed formal definition of such trigger strategies, see Chiappinelli and Neuhoff (2017).

The regulator evaluates the overall benefits of deviating against the threat of no new investments in the future. To this end, the government compares the welfare of compliance W^c to the welfare if it deviates W^d .

$$W^c \geq W^d \quad (14)$$

$$\sum_{s=t}^{\infty} \delta^{s-t} W(p_s = p^*, x_{i_s} = x_i^*) \geq \sum_{s=t}^{\infty} \delta^{s-t} W(p_s = 0, x_{i_{s=t}} = x_i^*, x_{i_{s \neq t}} = 0) \quad (15)$$

Transforming yields as compliance condition:

$$\sum_{s=t}^{\infty} \delta^{s-t} 2bep^* + \sum_{s=t+1}^{\infty} \delta^{s-t} \frac{2e}{\alpha} (1 + \delta) p^* Q \geq \sum_{s=t}^{\infty} \delta^{s-t} (ap^* - bp^{*2}) \quad (16)$$

The left hand side of equation (16) represents the total discounted environmental benefits that occur under compliance. Demand is reduced when the support level is positive, which occurs in every period with some environmental benefits captured by $2bep^*$. In contrast, only future investments are decision-relevant because the investments in period t have been made regardless. Thus, the environmental benefits from renewable energies $\frac{2e}{\alpha}(1 + \delta)p^*Q$ only accrue from period $t + 1$ onward. Naturally, past investments' environmental benefits also do not play a role.

The right hand side shows the benefits of deviating: consumer surplus is increased since no more support is paid. Importantly, this already begins in period t , even though new investments have potentially still been triggered in period t , to which the regulator is not paying the promised support. Equivalently, the regulator also does not pay any longer for generation from investments made in period $t - 1$, which are also still eligible to support in period t .

4 The role of policies and targets

We analyze the effects that different support policies and explicit renewable energy deployment targets have on compliance, costs, and renewable energy investments.

4.1 Time-inconsistency under different policy regimes

Policy regimes can support commitment equilibrium outcomes even though no governmental action is able to rule out deviations altogether. Yet, some policy frameworks allow for easier changes to announced support than others. An example that is easily integrated into the model are prohibitively high costs in case of “full” deviations: Beyond some threshold, e.g. a deviation on more than a certain share $(1 - \gamma)$ with $\gamma \in [0, 1]$ of commitments, firms in other sectors will also fear deviations by the regulator, which outweighs the gains from full deviations. Depending on the policy regime, this threshold can differ. The fear of contamination of other sectors' investments might be larger when the initial promise of the government is stronger, as the necessary political and legal barriers are harder to overcome. If the government is willing to get over large barriers to deviate from its renewable energy commitments, it might appear more likely to do so in other sectors as well. In contrast, when support levels are not clearly defined, deviations are harder to detect and understand, and deviations might be less likely to spread to other sectors.

The model is easily extended to incorporate limited deviations. Since the pay-offs under compliance remain unaltered, the optimal support level p^* and the optimal investment level x_i^* remain the same. However, the left hand side of the compliance inequality (16) – the environmental benefits of compliance – decrease. Whereas the second term on the left hand side of equation (17), the environmental benefits of new investments, does not change, the environmental benefits from a decrease in demand actually decrease with limited deviations compared to full deviations, as shown in equation (17). The simple reason is that in the first two periods after the deviation, the levy for commitments made until the time of deviation remains at γp^* rather than falling to zero. As of

the second period after deviation, the levy is zero once again and the benefits accrue just as with full deviations. Appendix 7.2 details the calculations.

Similarly, the benefits of deviating in terms of reduced levy payments decrease compared to full deviations. As of the second period after a deviation, the pay-offs are the same as under full deviations. After deviating, some levy γp^* remains, rendering deviations less attractive.

In total, compliance becomes more attractive when deviations are limited than when regulators can fully deviate. Demand is depressed after the deviation, leading to some environmental benefits on its own, but larger negative impacts on consumer surplus (which holds independently of the levy p and the remaining share γ by our assumption of negative impacts on welfare in the absence of investments; see appendix 7.1). The value of the left hand side decreases less than the value of the right hand side between equations (16) and (17). Appendix 7.2 provides details on the calculations.

$$\begin{aligned}
& eb\gamma p^*(2 + \delta) + \sum_{s=t+2}^{\infty} \delta^{s-t} 2bep^* + \sum_{s=t+1}^{\infty} \delta^{s-t} \frac{2e}{\alpha} (1 + \delta)p^*Q \geq \\
& \gamma(1 + \delta)ap^* - \gamma^2(1 + \frac{\delta}{2}b)p^{*2} + \sum_{s=t+2}^{\infty} \delta^{s-t}(ap^* - bp^{*2}) \quad (17)
\end{aligned}$$

We differentiate between three policy frameworks: Those where deviations are difficult for governments to implement as they must also change the constitution, frameworks where a – simpler – change of law suffices, and, lastly, such frameworks where only some rules need to be adjusted in order to deviate.

First, there are policy frameworks where the renewable energy policy itself stresses that it represents a remuneration stream that will not and cannot be altered over time and where, additionally, the constitution provides investment security through strong grandfathering rules. In order to change the constitution, which explicitly protects existing assets from legal changes, usually a qualified majority is required in parliament, posing a high threshold for retrospective changes of the renewable energy policy (Jakob and Brunner, 2014). This can be the case both for feed-in tariffs and feed-in premia. However, under feed-in premia, balancing costs remain with the investors, rendering the rules around balancing cost assignment prone to time-inconsistency issues (Neuhoff et al., 2016). Thus, with constitutional rights and respective policies, no full deviations are possible and γ in equation (17) is increased, rendering compliance more attractive.

Second, policy frameworks provide investors with an investment environment where regulators legally guarantee some support, but this support is not backed by constitutional grandfathering rights. Regulators can explicitly guarantee a specific remuneration level or a sense can prevail that overall profitability of projects is guaranteed, but not specific support levels. Without constitutional grandfathering rights and specified support levels, γ in equation (17) is lower than under the first set of policies.

Based on such arguments, Spanish investors who had invested before 2010 lost their case against the Spanish government that had retrospectively cut their support payments. The Spanish supreme court judges argued that the investors were entitled to profitability of their investments, but not necessarily the exact

level they had initially been promised. In particular, they stated that the adjustments were in line with “legitimate expectations” (El País, 2014). This has since been explicitly codified in the Spanish remuneration scheme and investors are guaranteed a certain markup over the returns of governmental long-term bonds (Spanish Ministry of Industry and Energy and Tourism, 2014). As early as between 2004 and 2007, the policy regime explicitly adjusted support levels based on the wholesale electricity price (Spanish Ministry of Economic Affairs, 2004), indicating a more subtle promise of support stability in comparison to explicit long-term stability of specific support levels.

Third, policy regimes like tradable green certificates promise remuneration streams that can be adjusted over time without retrospective legal changes. Under green certificate schemes, the number of certificates in the system defines the value of these certificates and, thus, the remuneration levels that renewable energies receive. Regulators can devalue certificates by flooding the market, e.g. by providing new certificates to foster new technologies. Alternatively, the regulator can decrease the demand for certificates by lowering (or not increasing) the number of certificates that power suppliers need to obtain, as was the case in Poland between 2010 and 2012 (Skarżyński, 2016) and in Romania in 2017 (Business Review, 2016). In any of these cases, the anticipated remuneration level is lowered during the lifetime of projects without the need for explicit retrospective legal changes. Therefore, γ in equation (17) is even lower compared to the other discussed policies.

These three policy frameworks hold implications for the overall costs of renewable energy deployment. When firms have imperfect foresight, the investment costs α increase when retrospective changes are easier to implement. In turn, this renders retrospective changes more likely, which increases the investment costs even further, creating a vicious cycle. This implies that *ceteris paribus* policies leaving more space for regulators to deviate lead to higher costs of deployment.⁸

4.2 Targets as commitment devices

National targets monitored or enforced by a supranational entity or the public can impact governmental behavior and can act as commitment devices. They do not directly affect the possibility of deviations, but they increase the costs at stake when considering deviations. Targets from a supranational level cannot usually be changed through changes of law at the national level. As Jakob and Brunner (2014) outline, such costs can be in terms of reputation, described by Barro and Gordon (1983), or financially.

The commitment benchmark changes. The firms’ profit functions are not touched in the first stage and the reaction functions remain the same as before. Welfare under commitment is altered, incorporating the potential fine from deviation if the target expansion \bar{x} is not reached. The fine f is multiplied with

⁸Citizen ownership is another means to alleviate time-inconsistency issues. When the regulator represents the interests of electricity consumers and those consumers also constitute electricity producers, the regulator also weighs producer surplus, reducing time-inconsistency issues.

the deviation from the investment trajectory target, \bar{x} .

$$W_t = \int_{p_t}^{p'_t} Q(z)dz - e(Q_t - \sum_{j=1}^J x_{j_t}(p) - \sum_{j=1}^J x_{j_{t-1}}(p)) - f[\bar{x} - \sum_{j=1}^J x_{j_t}(p) - \sum_{j=1}^J x_{j_{t-1}}(p)] \quad (18)$$

with $f = 0$ if $\sum_{j=1}^J x_{j_t}(p) + \sum_{j=1}^J x_{j_{t-1}}(p) \geq \bar{x}$. As long as the renewable energy target is not reached, the fine f works similarly to the increased environmental benefits of renewable energies, with the only exception that reducing demand does not inherently decrease potential fines.⁹ Therefore, solving for the optimal levy in the steady state yields as optimal levy:

$$p_{target}^* = \frac{a\alpha - bec - a(e+f)(1+\delta)}{b[2c(1+\delta) - (e+f)(3+8\delta+4\delta^2)]}(1+\delta) \quad (19)$$

Therefore, the levy under commitment is larger if the renewable energy target is not already reached without target. Similarly, based on the same reaction function as before, the investment level under commitment increases. If the renewable target is not yet reached without target, but the optimal levy and investment levels with target yield an expansion beyond the renewable target, then the corner solution $\sum_{j=1}^J x_{j_t}(p) + \sum_{j=1}^J x_{j_{t-1}}(p) = g$ maximizes welfare.

As a result, potential costs of not-achievement are added to the left hand side of equation (16) if the expansion target \bar{x} is not reached. Inequality (20) provides the compliance condition. The second term on the left hand side, the environmental benefits of renewable energy investments, is increased by the potential benefits of avoided fines.

$$\sum_{s=t}^{\infty} \delta^{s-t} 2be + \sum_{s=t+1}^{\infty} \delta^{s-t} \frac{2(e+f)}{\alpha} (1+\delta)Q \geq \sum_{s=t}^{\infty} \delta^{s-t} (ap_{target}^* - bp_{target}^{*2}) \quad (20)$$

Therefore, with target, compliance becomes more likely than without targets due to the increased benefits of renewable energies if the target is high enough. With a low target that is over-achieved in any case, the target does not increase the levy, the investment level, or the attractiveness of compliance.

The European Union's renewable energy deployment targets for 2020 are potentially relevant for national decision-making. In 2009, the European Union introduced the Renewable Directive. It included binding targets for the share of energy stemming from renewable energies both at the European level and at the individual country level. It specifies the share out of total energy use, incorporating the transport, heating, cooling and the electricity sectors.

The European targets are binding at the national level. These are based on each country's initial share of renewable energy in 2005 and their wealth, requiring stronger actions from wealthier member states. In 2005, Malta was the country with the lowest share of renewable energy, 0.2 percent, which it has to increase to ten percent by 2020, whereas the country with the second-lowest share, the UK at 1.4 percent, must increase its share to 15 percent. On the other hand, Sweden with the highest initial share of 40.6 percent, has to increase it

⁹When targets are set relative to demand, then the additional effect occurs that reducing demand lowers the renewable energy target, which is not captured by our model.

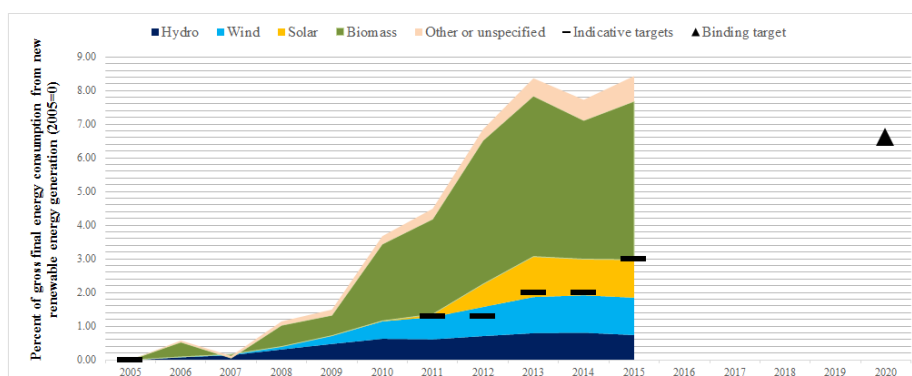


Figure 2: New generation from renewable energies since 2005 in Bulgaria, based on Eurostat (2017b)

to 49 percent and Latvia with the second-highest share of 32.3 percent needs to reach 40 percent. Between 2009 and 2020, there are additional non-binding targets, indicating whether countries are on track to reaching their 2020 targets.

These national targets influence the regulatory incentives for compliance as they might be fined by the European Commission. Alternatively, countries missing their targets can directly pay other EU countries that over-achieve their targets for statistical transfers of renewable energies, of which the first deals were closed in 2017, technically transferring renewable energy production from Lithuania and Estonia to Luxembourg (European Commission, 2017a,b). Equivalently, this implies a direct financial cost for countries that do not achieve their targets through their own renewable energy generation.

The 2020 targets only function as commitment devices when countries do not possess sufficient alternatives. The sustainability of biomass matters less in some countries (Ratarova et al., 2012). Using biomass seems to have been cheaper than wind and solar power in many Eastern European countries. Consequently, on the one hand, the European targets made biomass investments more attractive. On the other hand, they did not render compliance more likely for wind and solar power in these countries, as they can reach their targets more or less regardless of wind and solar power deployment.

Figure 2 shows the growth in renewable energy generation since the baseline year of 2005 in Bulgaria.¹⁰ Starting at an initial share of 9.4 percent of renewable energies, it stood at 18.2 percent in 2015, an increase of 8.8 percentage points. The share of biomass has grown significantly and together with a small uptake in hydro power generation almost suffices to fulfill the Bulgarian 2020 target of 16 percent (an increase of 6.6 percentage points since 2005).¹¹ Thus, targets

¹⁰Assuming that the growth in renewable energies for heating and cooling came from biomass.

¹¹Still, some wind and solar power have been installed. However, as no sustained growth in their capacities is required to reach the 2020 target, compliance is not attractive to the Bulgarian government. In 2013, it retrospectively introduced a 20 percent revenue tax for wind and solar power, yet not for biomass installations (Fouquet and Nysten, 2015). In parallel, it announced a moratorium for all new wind and solar power installations. The national constitutional court has since ruled that the retrospective revenue tax was unconstitutional (Fouquet and Nysten, 2015). In 2015, the government introduced a five percent fee on all

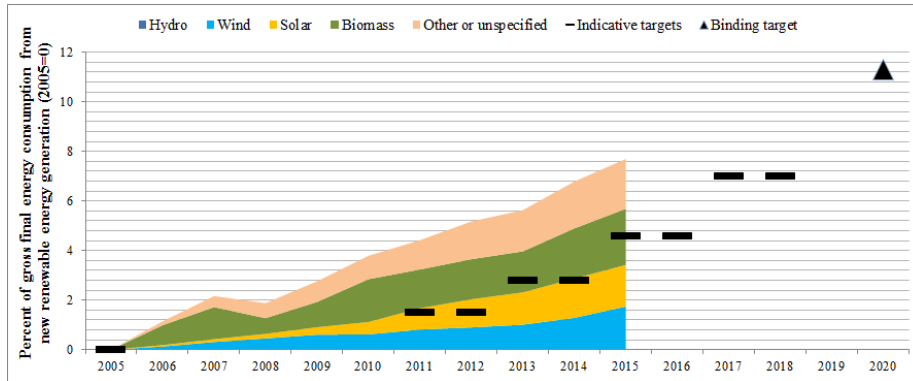


Figure 3: New generation from renewable energies since 2005 in Germany, based on Eurostat (2017b)

do not function as commitment devices when alternative, preferred technologies exist or if targets are reached ahead of time.

In most Western European countries, electricity from wind and solar power are the main viable renewable energy technologies to reach the 2020 targets.¹² Figure 3 depicts the increase in renewable energy in Germany since 2005.¹³ Even though biomass and other renewable energies, particularly energy from municipal waste, also play a role, new wind and solar power is considerably more prominent than it is in Bulgaria.

Figure 4 shows the growth in generation from renewable energies in Spain since 2005. Starting at 8.4 percent in 2005, the country initially strongly increased its renewable energy share. However, after retrospective cuts between 2010 and 2013 and the passing of a moratorium for new installations, the renewable energy share stagnated, such that the 20 percent target for 2020 is more difficult to achieve.

Countries that can only reach their targets through long-term favorable investment environments for specific technologies are more likely to stay committed to these technologies. If they have viable alternative technologies or reach their targets ahead of time, the potential fines f in equation (4.2) diminish. Thus, commitments are more credible in countries that are endowed with the potential for few alternative technologies and that lag behind enforceable, supranational targets.

sold electricity, which particularly affects renewable energy installations under feed-in tariffs as they are unable to pass on their increased costs (IEA, 2015).

¹²Finland and Sweden represent interesting exceptions as they have strongly increased their shares of biomass fuels in the transport sector.

¹³Assuming that the growth in renewable energies in heating and cooling comes from biomass. Approximating the generation and installation data from BSW-Solar (2016), we assume that two-thirds of the solar thermal production of 2015 was installed after 2005, in roughly equal annual amounts.

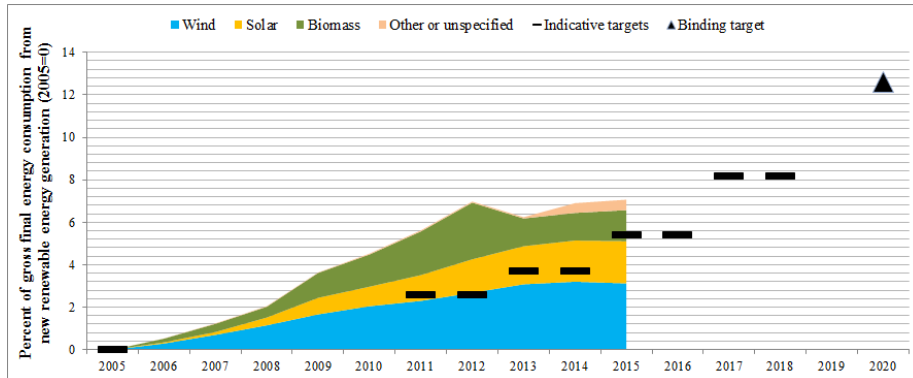


Figure 4: New generation from renewable energies since 2005 in Spain, based on Eurostat (2017b)

5 Why did Spain deviate when Germany did not?

We evaluate the time-inconsistency model for 2012 by numerically modeling the examples of Spain and Germany as these countries were frontrunners in renewable energy, but only Spain deviated. Germany in 2012 was the global number three in terms of installed wind power capacity and number one for solar, Spain was number four for wind power and number five for solar power (IRENA, 2017). With its renewable energy payments at about €34 per MWh in 2012 (Comisión Nacional de Energía, 2012), Spain conducted retrospective changes between 2010 and 2013. Germany did not, even though it had also experienced unprecedented growth in PV installations, increasing the levy three-fold from €11.3 per MWh in 2009 to €36.9 per MWh in 2012 (and subsequently to €52.7 per MWh in 2013) (Bundesnetzagentur, 2017). Why did and could Spain take these measures, whereas Germany did not?

As this analysis focuses on time-inconsistency, all past investments into renewable energies are taken for granted and not accounted for in terms of environmental benefits because they accrue in any case. This is also where potential time-inconsistency arises from: As the investments before 2012 have already been made, only their disadvantages, namely their costs, persist and matter for the decision-maker.

5.1 Parameters in 2012

In 2012, Spain had 22.8 GW of wind power and 6.6 GW of solar capacity, highlighting a focus on (then cheaper) wind power. Germany had 31.3 GW of wind power capacity, owing to rather constant growth in wind power capacities, and rather erratic growth in PV between 2009 and 2012, when 22 GW of the PV total of 32.8 GW were installed (IRENA, 2017).

The policy framework sets the backdrop against which investors invest and specifies how easily retrospective changes can be conducted. After some policy changes in the 2000s, Spain had a feed-in tariff for wind power, photovoltaics and concentrated solar power. Between 2004 and 2007, installations were not

granted specific remuneration levels, but multiples of the power price. This policy, based on a more general sense of profitability as laid out in section 4.1, allowed some deviations. Spain cut about 25 percent of its renewable energy payments from a total of €9.1 billion to €6.6 billion (Comisión Nacional de los Mercados y la Competencia, 2014, 2015). Since then, there have been conflicting court rulings. As detailed in section 4.1, the Spanish Supreme Court decided that Spanish investors were not eligible for compensation. International investors have been deploying the Energy Charter Treaty, which also led to different outcomes: On the one hand, one firm successfully argued that its revenues fell by two-thirds, thus it received compensation from the Spanish government. On the other hand, a similar case of another firm that had invested somewhat later was dropped on the grounds that “no reasonable investor could have the expectation that this framework would not be modified in the future and would remain unchanged” (Stibbe, 2017). Therefore, we assume that the Spanish regulators were able to cut around twenty percent of support payments, setting $\gamma = 0.8$ in equation (17), slightly less than the actual 25 percent, which, at least in some cases, seems to have infringed on investors’ legal rights.

Germany had a feed-in tariff that allowed firms the option to shift to a feed-in premium. As described in section 4.1, the focus of the legislation and the constitutional grandfathering rights was on providing stable support. This enables only small deviations. In order to compare factors other than the policy regime differences between Spain and Germany, we set $\gamma = 0.8$ for Germany as well, noting that this is an upper bound of the attractiveness of deviating.

The regulator compares the current and future benefits and costs of compliance and deviation based on equation (17). The payouts are calculated for all future periods until 2050, summing up the discounted welfare of the individual years.

5.1.1 Costs of renewable energy

We need to know how renewable energy generation x , costs c , power demand Q , and the renewable energy support p_t develop in the future under compliance. We use a detailed model created by Öko-Institut (2017) that provides estimates for the German renewable energy levy, which uses installation trajectories, power demand, and costs as inputs. In order to calculate the levy under compliance for Spain, we calculate how large the levy would have been without deviation and add approximated extra costs of new renewables installed after 2012 under compliance. Details of the calculations can be found in appendix 7.3.

5.1.2 Discount factor

The discount factor δ determines the relative weight of current and future periods and affects time-(in)consistent behavior to a large extent. Spain was at the height of the financial crisis in 2012. The government passed austerity measures in many sectors of the economy. Whereas the government previously filled the utility companies’ tariff deficit, it was severely constrained to do so. We use the average Spanish ten-year governmental bond rate, a standard indicator of the regulatory discount rate of 2012, which was 5.9 percent (Eurostat, 2017a). In Germany, this rate was considerably lower at 1.5 percent (Eurostat, 2017a).

5.1.3 Demand

In line with the model setup, we assume that demand Q is linear. We need to assume values for a and b . For both countries, we assume a demand slope of $b = 30 \text{ MWh}^2/e$. This is based on long-run inelastic demand elasticities of .16 in Germany and .3 in Spain, obtained from Madlener et al. (2011). For example, for Germany in 2012, this yields that a levy of €36 per MWh and at an exemplary household electricity price without levy of €230 per MWh reduces demand by about 2.5 percent. Based on this, we can calculate the increase in demand after a deviation, i.e. with a lowered levy. We use the same demand slope for Spain as for Germany because Spanish demand is lower, but the demand elasticity is almost twice as high. For Spain, this implies that the Spanish levy of €34 per MWh decreases demand without levy by about 4.3 percent. Moreover, based on realized demand volumes and the demand elasticities, we derive a , the demand without any levy. For Germany, this demand in 2017 was about 361 TWh,¹⁴ whereas it stood at 239 TWh in Spain. Details on the calculations can be found in appendix 7.4.

We treat the costs of renewable energies as levy in Spain as well, even though this is only partially correct: Utility companies bore the costs, but were only partially reimbursed through customers' electricity bills. They were stuck with a considerable chunk of the costs. This accumulated in a tariff deficit, which accumulated to €30 billion (Linden et al., 2014). These costs were eventually securitized and offered on the financial market. Ultimately, these costs are borne by electricity consumers (Reuters, 2010), such that the link between costs of new investments and levy is less direct than in Germany, but nevertheless exists.

5.1.4 Environmental benefits

The environmental benefits e from renewable energies (and to a much smaller extent from the reduction in demand) are the main factor driving and justifying renewable energy support. For both countries, we apply a shadow carbon price of €50 per ton. This by far exceeds the observed emission prices of the European emission trading scheme, for which many authors argue that they insufficiently reflect the true costs of pollution, e.g. Grubb (2012) and Edenhofer et al. (2017).

The carbon price is then multiplied with the carbon intensity for each country. In Spain, the average carbon intensity in 2013 stood at 303 grams of carbon dioxide equivalents per MWh, yielding $e = 15.15 \text{ €/MWh}$, which we apply for every period after 2012. In Germany, the intensity was 567 grams per ton (Moro and Lonza, 2017), implying that the environmental benefits of reduced conventional generation of $e = 28.35 \text{ €/MWh}$ exceed Spain's.

5.1.5 Investment volumes after 2012

In Spain, we observe a stand-still following the deviation and the simultaneously-introduced moratorium. Thus, we do not know what installation volume a regulator would have assumed. We choose 1500 MW for wind power, 750 MW for photovoltaics, and no new concentrated solar power. For Germany, we use the realized installation volumes for 2013-2016, even though those, particularly the PV boom between 2010 and 2012, certainly were not exactly expected.

¹⁴In addition, there are around 150 TWh of industry demand and self-consumption of electricity that is mostly exempted from the renewable levy.

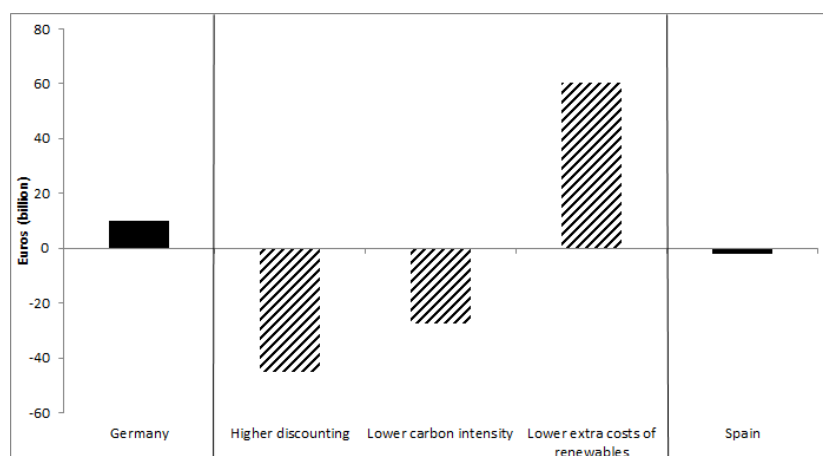


Figure 5: Drivers of the Spanish deviation. Positive values indicate that compliance is (rendered) more attractive, negative values that deviating is (rendered) more attractive.

5.1.6 Targets

As detailed in section 4.2, Spain and Germany were on a rather similar track toward reaching their 2020 obligations in 2012. Spain's renewable energy share was 14.3 percent in 2012, well on its way toward its target of 20 percent by 2020 (Eurostat, 2016). Germany's share in 2012 was 12.1 percent, similarly far on its path to reaching 18 percent by 2020 (Eurostat, 2016).

5.2 Results

In Spain, deviation was more attractive than compliance by €2 billion, whereas in Germany compliance was more attractive by €10 billion. Figure 5 visualizes the effects of the main drivers: Spain's higher discounting of future periods, Germany's relatively dirty fleet of conventional power plants, and Spain's higher electricity prices implying lower extra costs for renewable energies.

The higher Spanish discount factor is able to explain a significant part of the difference between Germany and Spain. Had Germany conducted the same discounting as Spain, deviating would have been more attractive also there. The higher discount rate would have made deviating €45 billion more promising. The high Spanish discount factor, for example, implies that pay-offs in 2020 only count 60 percent of the pay-offs in 2012, whereas in Germany, 2020-payoffs still count 86 percent as much.

The dirty German thermal power plant fleet turns out as very relevant as well. Germany with the Spanish thermal power plant fleet would have had large incentives to deviate, as the deviating would have been €27 billion more attractive than with the German power plant. This also implies that Spain would not have deviated, had it possessed the dirty German power plant fleet.

The extra costs of renewables are considerably lower in Spain, almost entirely driven by the higher wholesale electricity price. With the low Spanish extra costs of renewables, compliance pay-offs would have been around €60 billion higher in Germany. Figures 6 and 7 show the renewable energy levies in Spain

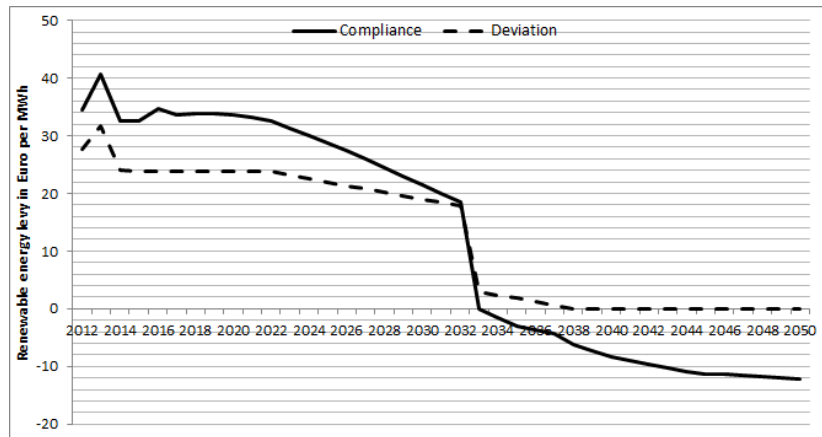


Figure 6: Spanish renewable energy levy, where compliance includes benefits of the merit-order effect of renewable energies installed after 2012

and Germany under compliance and deviation, also taking into account the induced merit-order of new installations. In Spain, the levy after deviating is the actual Spanish levy, which we can observe between 2012 and 2017. The levy under compliance lies higher since on the one hand, costs have not been cut by 20 percent in 2012 and, on the other hand, because new installations after 2012 are supported. The levy does not increase anymore after 2013 even under compliance. The reason is the Spanish wholesale electricity price, which stood at €44 per MWh in 2012 and increased to about €51 per MWh in 2017 (OMIE, 2018), reducing support costs as the difference between power price level and support level decreases. In Germany, the opposite happened. Power prices declined strongly from €55 per MWh in 2012 to around €30 per MWh in 2017 and the levy for new investments, despite their relatively low costs, increases somewhat until the early 2020s and only falls thereafter. Therefore, the extra costs for renewable energies, i.e. the difference between the costs of new installations and the power price, is much smaller in Spain, rendering compliance more attractive there.

Due to the high Spanish price level and the falling costs of renewable energies, renewable energies become cost-competitive when considering their environmental benefits as early as 2020 for wind power and 2029 for solar power. The date for solar power is later since the costs consist of a combination of utility and small-scale installations, where utility-scale solar becomes cheaper than the power price beforehand already. In Germany, power prices are lower but environmental benefits are larger. Wind power is cost-competitive in 2020 and the mix of utility- and small-scale solar power in 2027.¹⁵

When adding a fine for breaching the countries' 2020 targets, both countries become more likely to comply, but the effect is considerably larger in Germany. Through Germany's low discount rate, the potential fines – only starting in 2020 – weigh 25 percent heavier than in Spain. While the pay-offs after 2020 represent almost three quarters of all pay-offs in Germany, they only represent

¹⁵Assuming that due to simultaneity of renewable energy supply, they produce at only 80 percent of the wholesale power price.

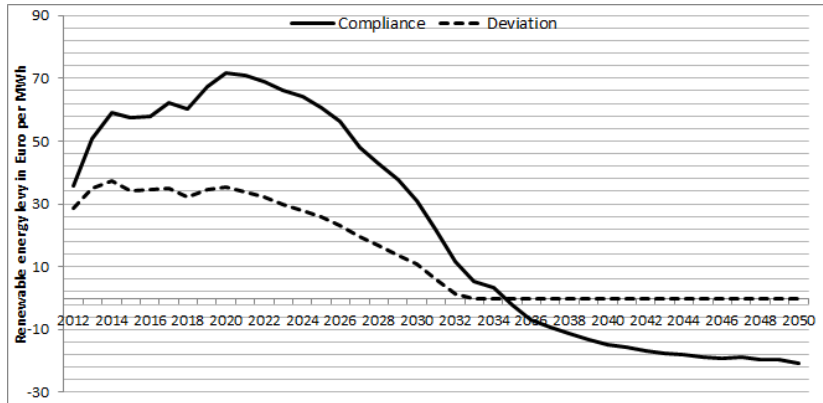


Figure 7: German renewable energy levy, where compliance includes benefits of the merit-order effect of renewable energies installed after 2012

58 percent in Spain.

6 Conclusion

Time inconsistency can arise for renewable energy investments and deter investments. In light of large investment needs, it is crucial that policy-makers address time inconsistency issues through policy frameworks.

We develop a dynamic regulatory game where the regulator optimizes welfare by announcing and setting renewable energy support, while firms invest in renewable energies. While, with open loop strategies, the regulator always deviates, trigger strategies can induce compliance if environmental benefits of future investments outweigh the costs of old and new investments. Governmental behavior, thus, hinges on the environmental benefits of future investments. If the expected renewable energy output and its environmental pay-offs are sufficiently large and firms do not invest after regulatory deviations, governments do not deviate from their announced policies.

Some policies make it easier for the regulator to deviate, whereas others tie the hands of the regulator more tightly. Firstly, sliding premia and feed-in tariffs that stress specific support levels together with grandfathering rules guaranteed by the constitution leave the least space for regulatory deviations. Secondly, sliding premia and feed-in tariffs with a more vague expectation of general profitability based on certain power market characteristics, like the wholesale electricity price, give the regulator some flexibility with respect to remuneration levels. Through legal changes, remuneration levels can be adjusted to a certain extent. Thirdly, green certificate schemes provide regulators with the ability to adjust support levels *ex-post* more easily still. The rules of the system, like the number of certificates for new installations or the obligations for electricity retailers, can be adjusted relatively easily without explicitly interfering with firms' property rights.

Moreover, we show that national, binding deployment targets stemming from a supranational entity like the EU can make compliance more attractive for governments as their stakes are increased. However, we also demonstrate that

this holds exclusively when only limited renewable resources are available to reach those targets as governments can otherwise simply shift the focus to other renewables.

In a numerical application, we identify the reasons why Spain conducted retrospective cuts to its renewable energy support, while Germany did not. The model suggests that on the one hand, the extra costs of renewable energies were actually considerably lower in Spain due to the higher wholesale electricity price, rendering compliance more attractive in Spain. However, on the other hand, this is outweighed by the dirtier German conventional power plants, which increase the environmental benefits of renewable energies in Germany. Most importantly, the larger myopia of the Spanish regulator, caused by high discounting during the financial crisis of future benefits of sustained renewable energy deployment, rendered deviating more attractive. These factors were combined with an enabling policy regime that left some space for retrospective changes.

Questions remain how to make compliance more attractive for regulators. One approach might be Contracts for Differences – existing in the UK – where firms have to pay back the regulator when power prices lie above support levels. If the general power price level increases while costs of renewables decrease, regulators have incentives to keep renewables inside support schemes and deviating becomes less attractive. Additionally, the effects of differing discount rates between the regulator and firms might extend the existing analysis and allow for interesting scenario analyses.

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7 Appendix

7.1 Levy condition

We assume that in the absence of investments into renewable energies, the regulator optimally sets the levy to zero since any positive support level would decrease welfare. The rationale is that such additional levies on the electricity price might well be in place, but they exist independently of the renewable energy levy. A simple example is an energy efficiency levy, which seeks to curb demand, that is implemented independently of the renewable energy levy. However, the renewable energy levy still also curbs demand, but the regulator will only set a positive level if the investments into renewable energies “are worth it”.

This assumption means that any increase in the levy p_t that is not accompanied by an increase in the investment level at some point has a negative impact on welfare. As this must hold in every individual period, it also holds in the (discounted) sum of period pay-offs. We assume the following holds in every period t :

$$\frac{\partial W_t}{\partial p_t} \Big|_{\left(\frac{\partial x}{\partial p_t} = 0\right)} = \frac{\partial}{\partial p_t} \int_{p_t}^{p'_t} Q(z) dz - e \frac{\partial Q_s}{\partial p_t} < 0 \quad (21)$$

It follows that without investments into renewables, curbing demand decreases consumer surplus more than it increases environmental benefits. Welfare from setting a zero levy $W_t(x = 0, p_t = 0)$ is larger than welfare with any positive levy $W_t(x = 0, p_t \neq 0)$ when there are no investments into renewable energies.

$$\int_0^{p'_t} Q(z) dz - ea > \int_{p_t}^{p'_t} Q(z) dz - eQ_t \quad (22)$$

7.2 Limited deviations

With limited deviations, as of period $t + 2$, the pay-offs are the same as under full deviations and only the pay-offs in t and $t + 1$ are altered. The impact of renewable energy investments remains the same as before in any case as no new investments take place after a deviation.

As some share of the levy remains in place in period t and period $t + 1$, the left hand side of equation (16) decreases because of the environmental benefits of reduced demand. In period t , these benefits are $2eb\gamma p^*$, i.e. per period the same as before but multiplied with γ and, thus, lower than under full deviations. In $t + 1$, only the effect of p_t prevails, which is discounted and, therefore, accrues to $\delta\gamma bep^*$.

Analyzing the right hand side of equation (17), in period t , the regulator pays out γp_t for investments from period t and γp_{t-1} for investments from the previous period. Therefore, the benefits of deviating decrease as some costs remain. The negative effect on consumer surplus is $\gamma ap^* - \gamma^2 p^{*2}$. In period $t + 1$, γp_{t-1} continues to depress demand by $\gamma ap^* - \frac{1}{2}\gamma^2 p^{*2}$. Demand reaches the same level as under full deviations as of period $t + 2$.

7.3 Levy calculation

To calculate the levy under compliance for Germany, we adjust the model in several ways: First, we update the cost estimates for renewable energies in light of the country’s most recent auction results. Generally, this implies lower costs than previously assumed. We assume wind onshore to cost €41 per MWh by 2025, PV on average between small-scale roof-top installations and ground-mounted installations €67 per MWh and offshore wind power €45 per MWh. Following Öko-Institut (2017), the

new installations follow the national target corridors of 2500 MW of onshore wind power annually, 2500 MW photovoltaics, and a total of 14 GW of offshore wind power capacity between 2017 and 2030. We assume that after 2035 support is no longer required, simplifying the calculations and resembling the current cost trends. Knowing the support lifetimes of the new installations through 2035, we can derive the support levels until 2050.

For Spain, we combine data from multiple sources to derive the potential renewable energy levy until 2050: we assume a simplistic capacity expansion of 1500 MW of new wind power and of 750 MW of PV per year, roughly reflecting the higher national weight on wind power deployment and the lower overall installation volume than in Germany. The deployment costs are derived from differences in costs in 2012: New wind power installations were about four percent more expensive per kWh in Spain than in Germany, PV was 16 percent more expensive. Spanish wind and solar conditions are superior to Germany's, but the policy regime leaves more room for retrospective changes, thus increasing the costs of financing.

Renewable energy generation reduces the overall power price. We impute this implicit merit order effect, which dampens the renewable energy levy. Cludius et al. (2014) show that in 2015, Germany's 176 TWh of renewable energy generation dampened the power price by about €15. This effect varies with the generation mix and the flexibility of the system. For simplicity, we assume the merit order effect of €0.085 per TWh as constant.¹⁶ We add this merit-order effect to the renewable energy levy in order to capture the entire electricity price effect of renewable energies.

7.4 Demand calculation

Following Öko-Institut (2017), German demand develops until 2021 according to the TSO's trend scenario (Energy Brainpool, 2014; Leipziger Institut für Energie, 2016; Prognos, 2014); i.e. the demand paying the renewable levy decreases slightly from 356 TWh in 2016 to 322 TWh in 2021. We assume subsequent demand remains constant due to the counter-acting effects of increased energy efficiency and self-consumption of PV power, on the one hand, and electrification of the transport and heating and cooling sectors, on the other hand. However, these values are realized demand values that take into account the existing renewable energy levy. Accordingly, we calculate the demand level without renewable energy levy, a .

In 2015 and, thus, after the deviation, Spanish demand was 232 TWh (Eurostat, 2018), which we for simplicity assume as constant in the following years. Calculating the electricity demand under compliance needs to be done vice versa as Spain did deviate in the early 2010s, such that the realized demand is based on a levy that is already reduced by 20 percent. We start with the realized demand values, based on Eurostat (2018), which gives us the demand Q after deviation. Knowing the renewable energy levy p under deviation and compliance and b , we can thus calculate how large demand would have been without deviation. For example, Q would have been 229 TWh in 2015.

¹⁶Spain's electricity sector is smaller than Germany's, thus, we would expect a larger merit-order effect there. However, to the authors' best knowledge, no existing research analyzed both countries' merit-order effects with one approach. Analyses with different methodologies reach vastly different results, e.g. Gelabert et al. (2011) and Sáenz de Miera et al. (2008), who find much larger effects.