Renewable energy and cooperation mechanisms

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Abstract

This report compiles the micro economic basics behind cooperation mechanisms for member states of the European Union in terms and practice. In the first chapter the three cooperation mechanisms are explained and evaluated. The second chapter goes into the mathematical side of the cooperation mechanisms. It starts with a simple cost supply curve and its surface for one member state and eventually it is built up to an arbitrary number of member states. Chapter three gives an explanation and an application of SDE+ regulation of the Dutch government with the cooperation mechanisms.

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1

Introduction

Human life on earth needs energy for many objects that need an energy source to work, like cars and cookers. Since decades the oil and gas we have been using, has been extracted from deep below the ground. And for many years now the alarm bell has been going on for the ending stock of fossil fuels. A renewable energy source is a source with unlimited stock, it is naturally replenished. Examples of renewable energy sources are solar energy, hydropower, tidal and wave power and geoterminal energy.

In 2009 the European Commision set the Directive 2009/28/EC, in which the binding target of 20% in 2020 of renewable energy of the total energy consumption in the European Union is set. This to be prepared for the ending stock of fossil fuels in the future and being self-supported in the European Union. Also in this Directive an introduction of cooperation mechanism between member states is given. These mechanisms are designed to make optimal use of renewable energy sources and the open European market. The model *Impact of cooperation mechanisms on the direct support costs of renewables deployment* [2] picks these mechanisms up to introduce the micro economic side of the cooperation mechanisms. And the Dutch government is interested in incorporating these cooperation mechanisms into its SDE+ regulation. The SDE+ regulation is a subsidy regulation for investors in renewable energy. With this regulation the Dutch government wants to attract investors in renewable energy to help to reach the domestic target of 14% of the Netherlands by 2020.

2

Cooperation mechanisms

In 2009, the European Commission set the binding 20% target of renewable energy of the total energy consumption in the European Union in 2020. Each Member State (MS) has a domestic target of the total of 20%. These domestic targets do not always reflect the renewable energy source (RES) potentials of the Member States. The availability of renewable energy like biomass, wind, hydro, tidal, wave, and solar varies significantly across the different member states. This results in an imbalance in costs between Member States to reach their domestic targets, which is caused by differences in RES potentials and costs for producing renewable energy.

With the aim of balancing the distribution of costs, three cooperation mechanisms are formed which are allowed by the Directive. The mechanisms allow member states with a low or expensive RES potential, to partially fulfill their RES target in other countries with higher RES potential or lower production costs. Each member state has potential RES Target, based on for instance their domestic target and costs of producing renewable energy. Based on these numbers a country is a user country or a host country when a mathematical comparison is made between the RES potentials of possible MSs that will cooperate. For the explanation of the three cooperation mechanisms the terms 'host country' and 'user country' can be used and they are introduced in RES4LESS [5]. A host country is a Member State which is expected to have low-priced surplus renewable energy that could be sold via cooperation mechanisms. A user country, conversely, is expected to have high costs to reach their target of renewable energy. The three cooperation mechanisms are called Joint Project, Joint Support Scheme and Statistical Transfer. An explanation of the three terms is given below.

Joint Project (JP)
Joint Projects are project-based agreements between two or more member states , defining that the renewable energy production of a renewable energy installation in one country will fully or partly count towards the RES target of another country. The user country may provide financial support for the RES project in the host country.

Joint Support Scheme (JSS)
Member States can unify or coordinate their support schemes and (virtually) split the produced renewable energy for target compliance.

Statistical Transfer (ST)
This option means that renewable electricity, which has been produced in one member state, is virtually transferred to the RES statistics of another Member State. These added statistics count towards the national RES target of the latter member state.

There is a fourth cooperation mechanism named Joint Project with third countries, but it is different in use then the others. A third country doesn't have a target like all MSs of the European Union (EU) have and a physical transfer has to be made to make cooperation possible. This cooperation mechanism is therefore not implemented into the model 'Impact of cooperation mechanisms on the direct support costs of renewables deployment', that is used in the next chapters.

2.1 Criteria and evaluation

There are four groups of criteria used to point out the differences between the cooperation mechanisms between MSs which are explained down here [3].

Effectiveness
The most important criterion for a cooperation mechanism is its effectiveness. The cooperation mechanisms should facilitate overall RES target achievement by allowing RES exchange within Europe. The political side of achieving these targets is to enable or even force member states to meet their national RES targets. The two ways to achieve this are providing MSs with cooperation mechanisms options and leaving the MSs the possibility to improve the design of their national support instruments.

Cost-effectiveness
Cost-effectiveness is the main economic criterion. This because cooperation mechanisms help to develop untapped low-cost RES potentials in Europe, which would potentially decrease to overall costs of achieving the RES targets.

Political criteria
To find wide support for the proposed cooperation mechanisms some important political criteria for a MS need to be met. For instance the sovereignty on the national RES policy is one major criterion that is defined by the European MSs. On the other hand realizing a single European market is one of the widely accepted aims of the European Union. A more common political criterion is the public acceptability of governmental policies. Fairness of equity of policy stands out in this criterion. The key issue in this regard is to split RES costs and benefits between the host country and user country. RES installations create some local costs and benefits that cannot be transferred to other MSs. From the perspective of the host country, a cooperation mechanism seems only attractive if the benefits outweigh the local costs and disadvantages. And from the perspective of the user country, cooperation mechanisms are attractive if the price of the foreign renewable energy is lower than the domestic price and certain acceptance problem for a RES installation in the user country. So in short the cooperation mechanism needs to provide a split of costs and benefits that combine these two interests. Another issue is the spending of public or consumer money on RES support.

Technical criteria
Technical criteria are used to evaluate to what extent the cooperation mechanisms can easily be put in to practice. Terms like easy implementation and transparency are central in this criterion.

To be able to evaluate the performance of Joint Projects, design features of the projects need to be made first. Strong principals of this cooperation mechanism is that it leaves MSs their sovereignty on domestic RES potentials and policies. And also the time that is needed to implement a Joint Project is probably faster than needed for joint support schemes, because of certain aspects like technologies and volumes. But on the other hand the weaknesses of this mechanism is that it is negotiated from case-to-case, which could lead to complexity and complicated agreements of RES support in Europe.

Joint support scheme gives a similar result as Joint Projects. It does stimulate the idea of a harmonization of RES support in Europe. But the biggest difference is that MSs find it difficult to negotiate them, because they have to agree on all aspect of a common support scheme.

Statistical transfer is the simplest mechanism between MSs. MSs keep their sovereignty and it is easily put into practice. A major disadvantage is that it relies totally on the national support schemes of the MSs to develop additional RES potentials.

After evaluating the cooperation mechanisms with these criteria it is clear that there is no clear cooperation mechanism that stands out. One uncertainty to take into account that only a handful of cooperation mechanisms are taken into practice yet. For instance Norway and Sweden started in 2012 as first and the only one yet with a Joint Support Scheme.

3
The model

The model 'Impact of cooperation mechanisms on the direct support costs of renewables deployment' [2] is a micro-economic model, in which three cooperation mechanisms are explained in mathematical terms. There is a fourth cooperation mechanism, named Joint Projects With Third Countries, but it is not included in the model. As earlier mentioned the EU set a twenty percent target of renewable energy of the overall energy consumption by 2020. Many member states including the Netherlands are currently not on the level of renewable energy to reach their domestic target by 2020. This model explains the possibilities to cooperate with another Member State (MS) of the EU to improve their levels of renewable energy.

3.1 Static model

This section explains the basics of the micro-economic model for cooperation mechanisms between member states. It is clarified with the supply and demand of renewable energy. In the model user countries en host countries interact to determine the quantity of renewable energy sold in a market and the price at which it is sold. The Cost Supply Curve (CSC) in this model shows the correspondence between the quantity of renewable energy and the production costs. The production costs are the cost for running the machine, but also factors such as the price that is payed for building the renewable energy installation.

A formula exists out of variables and coefficients. The variables are different for each specific MS_i. The number i stands for a specific MS and is an element of $[1, N]$. N is the amount of member states. The following variables are used to estimate direct costs and benefits of cooperation mechanisms:

- Energy potential (u) in TWh
- Costs (c) in ct€/kWh
- Electricity marketprice (p) in ct€/kWh

An example of a basic cost supply curve is given in Figure 1. This graph shows the correspondence between the Renewable Energy Source - Electricity (RES-E) potentials on the horizontal axis and the levelized production costs on the vertical axis. The symbols that are used are respectively u and c as shown above as used variables. In this case electricity is used as the energy potential. A coordinate in the graph is (u_i, c_i) for a MS_i. The function is called the Cost Supply Curve and is used as a line. The dot on the CSC represents the RES-E target of the domestic RES target of MS_i. The subscript for the RES-target coordinates is not i as usual, but T_i as shown above the dot. After the the RES-target the function f_i continues as a striped line. The energy that can be produced after the target is optional for MS_i. The dotted line under the CSC stands for the electricity price (p_i) in MS_i.

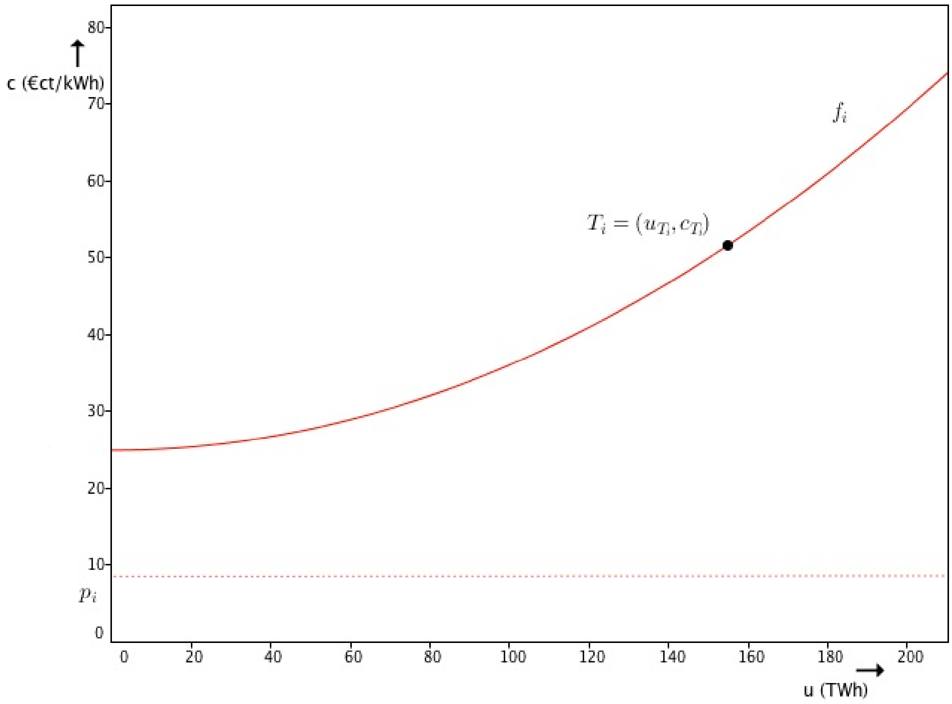

Figure 1: Simple Cost Supply Curve for MS_i

The area between the CSC f_i and p_i. This area (S_i) is used to compare member states with each other and see if cooperation is profitable. The equation for S_i is as follows:

$$\begin{aligned} S_i(u_{T_i}) &= \int_0^{u_{T_i}} \Big(f_i(u) - p_i\Big) du \\ &= \int_0^{u_{T_i}} f_i(u) du - p_i u_{T_i} \end{aligned} \tag{3.1}$$

Another notation that is used in the micro economic framework for cooperation mechanisms is $f_i^{-1} = g_i$. This is used to describe the same CSC in the potentials and the costs domain. In micro economic terms the explanation is that g_i reflects the amount of renewable energy a certain MS_i is willing to buy at a given price during a specified time period. With the use of g_i it is for instance easier to sum up two CSCs in the potentials for two different member states.

To make a mathematical model, assumptions has to be made. The following assumptions are used in Figure 1 and all the formulas for the cooperation mechanisms:

- f_i is a continuous, differentiable and invertible function
- $p_i \in \mathbb{R}$ and is constant
- S_i provides a good estimate of the total yearly support costs associated with the target.

The explanation why these assumption may yield is done in Chapter 4.

3.2 Joint Support Scheme

When two member states decide to implement a JSS the following equations can be made for the Cooperation case (C):

$$g_C(c) = g_1(c) + g_2(c)$$

$$u_{T_C} = u_{T_1} + u_{T_2}$$

$$c_{T_C} = f_C(u_{T_C}) = [g_C]^{-1}(u_{T_C})$$

The first formula $g_C(c)$ sums up the two domains of the CSCs of MS_1 and MS_2. This results in the domain of the cooperation CSC $g_C(c)$ for the JSS. The second formula u_{T_C} gives the cooperation target with a summation of the two single-country targets. The last formula c_{T_C} gives the total costs of reaching the joint target u_{T_C} with the use of the two formulas above. The function $f_C(u_{T_c})$ is the CSC for the cooperation case in a JSS.

When this kind of cooperation will take place the production levels will change in the two countries. Figure 2 [Number referentie] visualizes this situation. In this example MS_2 has a higher renewable energy target and higher production costs than MS_1. $u^*_{T_1}$ and $u^*_{T_2}$ are the new RES-E target for MS_1 respectively MS_2. The new targets can be calculated with the equation $u^*_{T_i} = g_i(c_{T_C})$ with i represents a 1 or a 2 for MS_1 or MS_2. A visual explanation for this formula is given in Figure 2. The new CSC f_C has the cooperation target T_C. As explained earlier f_C is the summation of the two single-country CSCs. To get back from f_C to f_1 and the new target $T^*_1 = (u^*_1, c^*_1)$ only the function g_1 is needed. The output of $g_1(u)$ gives the coordinate c, that combines to that u so that it is a dot on the function f_1. The same yield for MS_2 and its CSC f_2.

In Figure 2 can be seen that MS_2 is a user country and MS_1 a host country, because the new RES-targets are respectively lower and higher than the original RES-target.

Take into account that $u_{T_1} + u_{T_2} = u_{T_C} = u^*_{T_1} + u^*_{T_2}$. In both cases the cooperation target T_C is reached. The first case is the No Cooperation case (NC), inwhich everthing stays

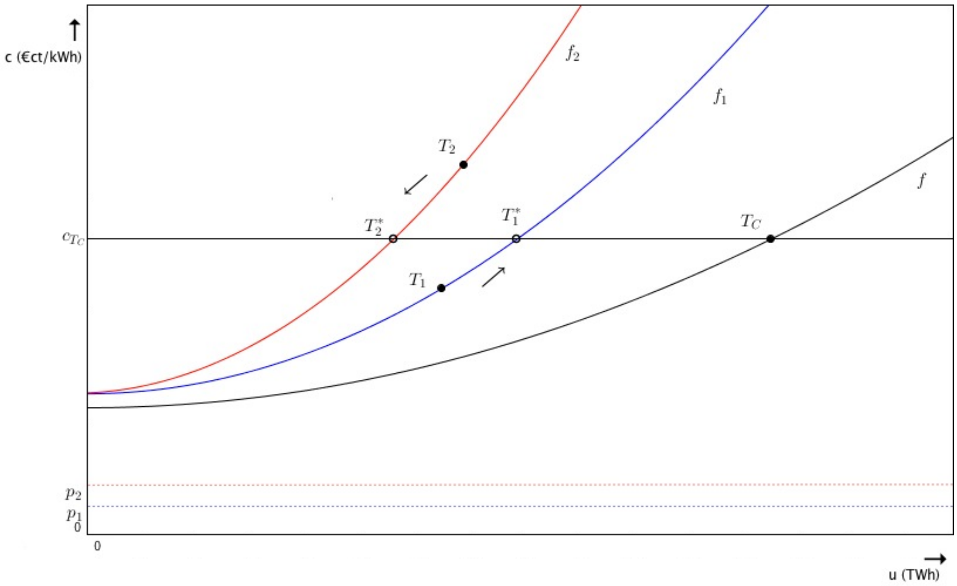

Figure 2: JSS - 2 MSs separate markets

the same with T_1 and T_2 as RES-E targets for respectively MS_1 and MS_2. The second case is the Cooperation case (C), inwhich the target T_1 changes into T_1^* and T_2 into T_2^*. The difference is that the C case might be more profitable than the NC case. The way to find this out is to calculate the differences between the total costs of the both cases. This is done with the use of the formula (3.1).

The formula $\Delta S = S_{NC} - S_C$ will calculate the amount of money that can be saved in a cooperation case. S_{NC} is the formula for the total costs in de NC case, that is, the summation of the area $S_1(u_{T_1})$ and the area $S_2(u_{T_2})$ and the same yields for S_C in the C case. The equations are as follows in mathematical terms:

$$\begin{aligned} S_{NC} &= S_1(u_{T_1}) + S_2(u_{T_2}) \\ &= \int_0^{u_{T_1}} f_1(u)du - u_{T_1}p_1 + \int_0^{u_{T_2}} f_2(u)du - u_{T_2}p_2 \end{aligned} \tag{3.2}$$

$$\begin{aligned} S_C &= S_1(u_{T_1}^*) + S_2(u_{T_2}^*) \\ &= \int_0^{u_{T_1}^*} f_1^*(u)du - u_{T_1}^*p_1 + \int_0^{u_{T_2}^*} f_2^*(u)du - u_{T_2}^*p_2 \end{aligned} \tag{3.3}$$

Using the equations S_{NC} and S_C from above ΔS becomes:

$$
\begin{aligned}
\Delta S &= S_{NC} - S_C \\
&= \Big(\int_0^{u_{T_1}} f_1(u)du - u_{T_1}p_1 + \int_0^{u_{T_2}} f_2(u)du - u_{T_2}p_2\Big) \\
&\quad -\Big(\int_0^{u^*_{T_1}} f^*_1(u)du - u^*_{T_1}p_1 + \int_0^{u^*_{T_2}} f^*_2(u)du - u^*_{T_2}p_2\Big) \\
&= \Big(\int_0^{u_{T_1}} f_1(u)du - u_{T_1}p_1 + \int_0^{u^*_{T_1}} f^*_1(u)du - u^*_{T_1}p_1\Big) \\
&\quad +\Big(\int_0^{u_{T_2}} f_2(u)du - u_{T_2}p_2) + \int_0^{u^*_{T_2}} f^*_2(u)du - u^*_{T_2}p_2\Big) \\
&= -\int_{u_{T_1}}^{u^*_{T_1}} f_1(u)du \; + \int_{u^*_{T_2}}^{u_{T_2}} f_2(u)du \\
&\quad -\Delta u\big(p_2 - p_1\big) \qquad (3.4)
\end{aligned}
$$

In the last simplification $\Delta u := u^*_{T_1} - u_{T_1} = u_{T_2} - u^*_{T_2}$ is used. This can be derived from $u_{T_1} + u_{T_2} = u_{T_C} = u^*_{T_1} + u^*_{T_2}$. With u_{T_C} the total cooperation target. To make a noticeable difference between several ΔS formulas. It is better for instance to make use of subscripts. In this situation it could be ΔS_{JSS}.

Reformulation of ΔS

There is a reformulation of the formula ΔS so that it becomes particularly useful and meaningful for a clear explanation of how a JSS can be used. For the reformulation the next substitution rules are used:

for f_1 $\quad u \rightarrow (u + u_{T_1})$

for f_2 $\quad u \rightarrow (u_{T_2} - u)$

The CSC of MS_1 is shifted to the left with a distance of u_{T_1}. So the cost supply curve of MS_2 is flipped around u_{T_2} as a vertical axis and f_2 is now the demand curve of MS_2. In micro economic terms the demand curve is a function that reflects the amount of renewable energy a certain MS_i is willing to buy at a given price during a specified time period. As in the model equation (3.4) for the JSS with substitution (JSSs) can be rewritten as:

$$
\begin{aligned}
\Delta S_{JSSs} = \quad & \int_0^{\Delta u} \Big(f_2(u_{T_2} - u) - f_1(u + u_{T_1})\Big)du \\
& -\Delta u\big(p_2 - p_1\big) \qquad (3.5)
\end{aligned}
$$

After this part in the model the notation of $f_1(u + u_{T_1})$ and respectively $f_2(u_{T_2} - u)$ are changed in $\varphi_1(u)$ and $\varphi_2(u)$. This to make clear that the used functions are different than the used ones before, namely f_1 and f_2. With these changes of notation a new figure, Figure 3, can be made. Figure 3 gives an explanation of the substitutions with the old functions f_1 and f_2 as striped lines.

In Figure 3 all the used targets and associated costs are shown. The colored surfaces on the left and respectively on the right in Figure 4 are the outcome of formula (3.4) for ΔS

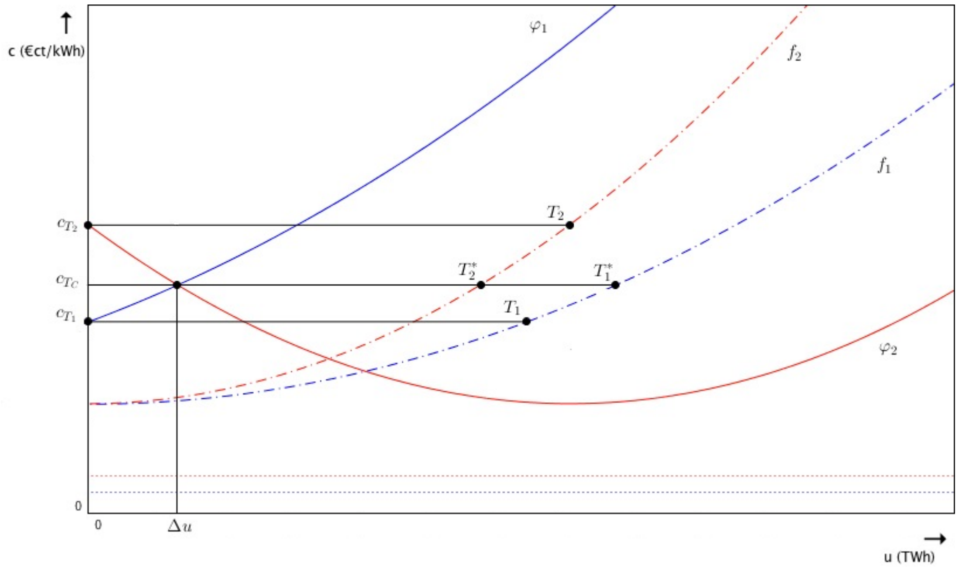

Figure 3: JSS - separate markets and substitutions

and the outcome of formula (3.5) for ΔS_{JSS_s}. Both the surfaces, green and gray, are the same, because of the chosen substitutions for the functions f_1 and f_2 so that the calculated area in both equations are the same. This reformulated case for a JSS is useful, because of the more simple integral for calculating the same surface ΔS. In Figure 4 both surfaces ΔS and ΔS_{JSS_s} are shown. The two gray areas and the green areas are similar.

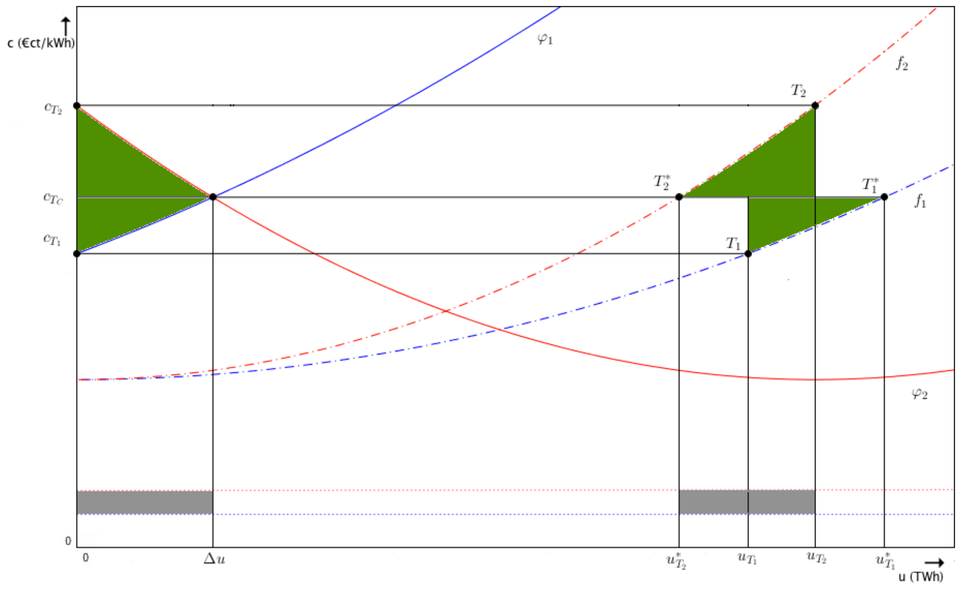

Figure 4: Comparison between ΔS_{JSS_s} and ΔS

Unified markets

As mentioned in de defenition of JSS in Chapter 1, MSs can decide to coordinate their support schemes or unify their support scheme.

In this last paragraph the option of a unified markets in a joint support scheme is explained. It gives an explanation of an extreme version of cooperation between MSs on the electricity market. MSs will unify their electricity markets and get a uniform price $\dot{p}$. In this unified situation a new formula for ΔS can be made and called ΔS_u as follows with the use of $\Delta S_u = S - \dot{S}$ with S as the NC case and $\dot{S}$ as the unified market cooperation case with unified electricity markets. To come to the last simplified formula the weighted average $\tilde{p} = \frac{p_1 u_{T_1} + p_2 u_{T_2}}{u_{T_1} + u_{T_2}} = \frac{p_1 u_{T_1} + p_2 u_{T_2}}{u_{T_C}}$ is used.

$$\begin{aligned}
\Delta S_u &= \Big(S_1(u_{T_1}) + S_2(u_{T_2})\Big) - \Big(\dot{S}_1(u_{T_1^*}) + \dot{S}_2(u_{T_2^*})\Big) \\
&= -\int_{u_{T_1}}^{u_{T_1}^*} f_1(u)du \; + \int_{u_{T_2}^*}^{u_{T_2}} f_2(u)du \\
&\quad -\Big(u_{T_1^*}\dot{p} + u_{T_2^*}\dot{p} - u_{T_1}p_1 - u_{T_2}p_1\Big) \\
&= -\int_{u_{T_1}}^{u_{T_1}^*} f_1(u)du \; + \int_{u_{T_2}^*}^{u_{T_2}} f_2(u)du \\
&\quad -\Big((u_{T_1^*} + u_{T_2^*})\dot{p} + \frac{u_{T_C}}{u_{T_C}}(-u_{T_1}p_1 - u_{T_2}p_1)\Big) \\
&= \int_0^{\Delta u} \Big(f_2(u_{T_2} - u) - f_1(u + u_{T_1})\Big)du - \Big((u_{T_1}^* + u_{T_2}^*)\dot{p} - u_{T_C}(\frac{u_{T_1}p_1 + u_{T_2}p_2}{u_{T_C}})\Big) \\
&= \int_0^{\Delta u} \Big(f_2(u_{T_2} - u) - f_1(u + u_{T_1})\Big)du + u_{T_C}\Big(\dot{p} - \tilde{p}\Big) \qquad (3.6)
\end{aligned}$$

3.3 Joint projects and Statistical transfer

The equations for the two other cooperation mechanisms JP and ST can be derived from the equations of JSS in Section 2. A CSC consists of segments and a JP can be one segment of the CSC, or a fraction of a segment or even multiple segments. In chapter 4 an extensive explanation is given of what a CSC in real life is.

ST is the easiest cooperation mechanism between MSs to implement. It is just a segment of a fraction of a segment of a CSC, but with this option the supply of renewable energy is limited.

3.4 Generalization amount of MSs in JSS

To scale the cooperation level up to an arbitraty number of countries most of the equations will change. When increasing the amount of MSs to N the sum of the targets becomes $u_{T_C} = \sum_{i=1}^{N} u_{T_i}$ and each MS_i has its own target u_{T_i}. Each MS_i changes its production from u_{T_i} to $u_{T_i}^*$. In this generalization case we define $\Delta u_i = u_{T_i} - u_{T_i}^*$. The Δu_i as used for two MSs can be called Δu, because the distance to both the new targets is the same. In the generalization case this unlikely to happen. But in every JSS the following formula is te same:

$$\sum_{i=1}^{N} \Delta u_i$$

This formula equals zero, because the total RES-E potentials in the NC case has to be the same as in the C case. In a JSS MSs with surplus potential will compensate the other MSs without surplus potential in their CSC. Figure 5 is an example of a JSS for three MSs with the associated new targets. In this example it is clear to see that Δu_1, Δu_2 and Δu_3 differ from each other.

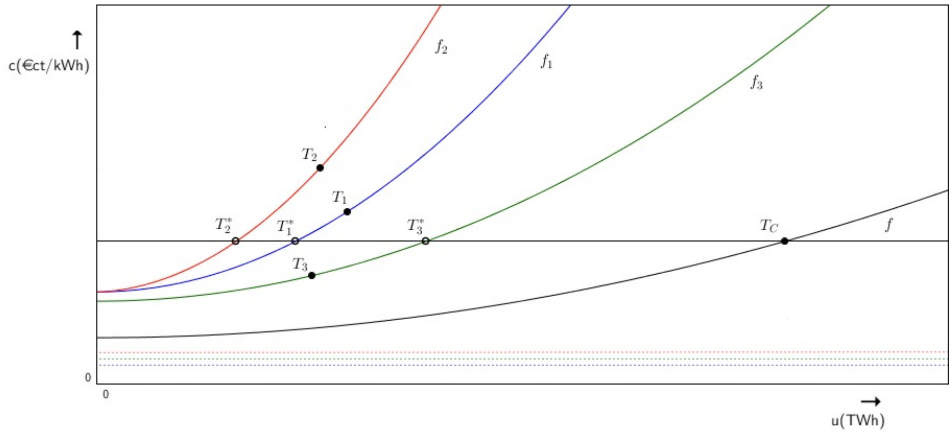

Figure 5: JSS - 3 MSs separate markets

Back to the arbitrary number of MSs the new equations for S_NC, S_C and ΔS will become:

$$
\begin{aligned}
S_{NC} &= \sum_{i=1}^{N} S_i(u_{T_i}), \\
S_{C} &= \sum_{i=1}^{N} S_i(u^*_{T_i}), \\
\Delta S &= \sum_{i=1}^{N} \left(\int_{u^*_{T_i}}^{u_{T_i}} f_i(u)du - p_i \Delta u_i \right).
\end{aligned}
\tag{3.7}
$$

In the subsection *Reformulations of* ΔS φ_1 and φ_2 are introduced. To generalize these formulas a distinction between host and user countries of the N MSs need to be made. A user country is a MS_i with $\Delta u_i \leq 0$ and a host country is a MS_i with $\Delta u_i \geq 0$. Therefor φ_1 becomes the summation of all the MSs that reduce their production and φ_2 the summation of all the MSs with an increas of their production. The generalized φ_1 and φ_2 are as follows and can replace the original ones in formula (3.5):

$$
\begin{aligned}
\varphi_1(u) &= \sum_{i:\Delta u_i \leq 0} f_i(u + u_{T_i}), \\
\varphi_2(u) &= \sum_{i:\Delta u_i \geq 0} f_i(u_{T_i} - u).
\end{aligned}
$$

4

Reality of assumptions

As mentioned in section 2 assumptions have to be made to be able to make a mathematical model. In this paragraph a deeper explanation is made of why you can or can not make a assumption like is done with the micro-economic framework for cooperation mechanisms and some possibilities how wrong assumptions can be fixed.

4.1 f_i is a continuous, differentiable and invertible function

A CSC of RE is not a continuous rising graph in reality like shown in Figure 1. It is a discrete collection of segments. Each segments is a RES with certain production costs. A segment is the summation of one or more RE installations. The first segment of the CSC has the lowest production costs and the costs rises with each segment. So the function is always a rising function.
The properties continuous, differentiable and invertible can not be assumed without a good explanation of how the approaching function f_i is made out of the segment function h_i. With this definition given, it is possible that the function f_i is continuous, but not differentiable and invertible at the same time. When taking these assumptions as true for f_i, then that can affect the total basis for all the formulas for cooperation mechanisms. Overall yields that assuming things a model needs, any possible model can be made. Take into mind that when looking to the reality of a made model like that, the model has a big chance to fail in reality.

4.2 $p_i \in \mathbb{R}$ and is constant

As mentioned earlier p_i is called the electricity market price. And it is well known that every market price is not constant. It depends on the supply and demand on the market. So p_i depends on the total deployed RES potential u_i. In this new situation p_i is called $p_i(u_i)$. The new equations for $S_i(u_{T_i})$ then becomes:

$$S_i(u_{T_i}) \quad = \quad \int_0^{u_{T_i}} f_i(u)du - p_i(u_{T_i})u_{T_i} \tag{4.1}$$

When a MS_i is going to cooperate with another MS_j, the original RES-E target in the potentials u_{T_i} changes into $u^*_{T_i} = u_{T_i} + \Delta u$ if MS_i is a host country and respectivily $-\Delta u$, if MS_i is a user country. With the approximation $\Delta u \ll u_{T_i}$ that will hold in most cases. It is a different story with JSS, because of the changes over the years within the cooperation. Now p_i can be expanded to the first order of the Taylor serie of $p_i(u^*_{t_i})$:

$$\begin{aligned} p_i(u^*_{T_i}) &= p_i(u_i) + p'_i(u_i)(u^*_{t_i} - u_{t_i}) \\ &= p_i(u_i) \pm p'_i(u_i)\Delta u \\ &= p_i(u_i) \pm \varepsilon_{p_i} p_i(u_{T_i})\Delta u \\ &= p_i(u_i)(1 \pm \varepsilon_{p_i} \frac{\Delta u}{u_{T_i}}) \end{aligned} \tag{4.2}$$

In this reformulation the elasticity of the electricity price ε_{p_i} with respect to a change in RES-E supply is used.

$$\begin{aligned} \varepsilon_{p_i} &= \frac{u_{T_i}}{p_i(u_{T_i})} \frac{dp_i}{du} \\ &= \frac{u_{T_i}}{p_i(u_{T_i})} \cdot p'_i \end{aligned} \tag{4.3}$$

A higher order of the Taylor series is not used, because adding more terms will make the equation less understandable. The ΔS with p_i that depends on the u_i becomes ΔS_{p_i} and is as follows:

$$\begin{aligned} \Delta S_{p_i} &= \int_0^{\Delta u} \Big(f_2(u_{T_2} - u) - f_1(u + u_{T_1})\Big) du \\ &\quad -\Delta u\Big(p_2(u^*_{T_2})/(1 \pm \varepsilon_{p_2}(\Delta u/u_{T_2})\Big) \\ &\quad -\Delta u\Big(p_1(u^*_{T_1})/(1 \pm \varepsilon_{p_1}(\Delta u/u_{T_1})\Big) \end{aligned} \tag{4.4}$$

4.3 S_i provides a good estimate of the total yearly support costs associated with the target

When making an assumption of a approaching function of the original one, a comparison between both functions has to be made and a margin has to be set. The area S_i for MS_i reflects the reality of the total yearly support costs (C) associated with the target, if it does not differ much from the original areas under the segments, of which the CSC f_i is built up. Without making a comparison between the original segment function h_i for MS_i and the approaching function f_i, the whole model is built up without a good base.
For instance h_i exists M segments with each an associated beginning energy potential u_k of the segment and a cost length c_k ($k \in M$). Then the total area under h_i is $\sum_{k=1}^{M}(u_k - u_{k-1})c_k$. To get the formula for the actual costs that are made to reach target $T_i = (u_{T_i}, c_{T_i})$, the last segment, which T_i consist, has to be split up. Lets call the last segment that is needed $l \in 1, ..., M$. The left part from l from the vertical line $u = u_{T_i}$ is used. So now the total costs are $C = \big(\sum_{k=1}^{l-1}(u_k - u_{k-1})c_k\big) + (u_{T_i} - u_{l-1})c_l$. The calculation of the deviation from the approaching costs in comparing with the actual costs (D_C) in

percentage can be done with the following equation:

$$\frac{C - S_i}{C} \cdot 100\% \tag{4.5}$$

To decide what percentage it may be depends on a lot of factors, for instance the total amount of money C that the functions h_i is about. Till now no margin has been set, so no conclusions can be made about the estimated S_i, the total yearly support costs associated with the target.

5

SDE+

The subsidy in the SDE+ arrangement is a calculation of the basic price minus the correction price. The basic price is based on the investment and production costs and a reasonable profit margin, divided by the expected amount of produced renewable energy. This price is defined for the total compensation period. The correction price is more complicated, depending in which category the energy is produced. In simple terms the correction price is the average of the electricity price from January to December in year x on the APX-energy exchange. But for most of the categories there has to be added imbalance charges ($0 < c \leq 1$). So that it covers unknown factors like wind. A lower energy price is defined to limit the compensation. This occurs when the electricity market price is equal or lower than the energy price. Each arrangement in this compensation system has a maximum amount of compensation. This maximum amount is set by the full load hours, the amount of hours that a production-installation produces at full rated power.
Down here the formula $q(p_a)$ for the subsidization in €ct per kWh depending on the market prices for renewable energy like electricity and gas. There is a simple correction price (5.1) defined and a complicated correction price (5.2). The difference between the two is that the complicated function has more variables, because there are renewable energy types that are unforeseeable take for instance solar and wind power. Within the SDE+ for these types there is worked with a prediction factor. In reality it can be that the prediction sun hours are not reached or it can be more. To compensate both cases the variables p_a, c and p_b are used and explained below.

$$q(p_a) = B - C_{p_a} \quad (5.1)$$

$$B - min\{p_a \cdot c, p_b\} \quad (5.2)$$

$q =$	subsidy per €ct/kWh
$B =$	basic price per €ct/kWh
$C_{p_a} =$	correction price €ct/kWh
$min =$	minimum
$p_a =$	average market price of twelve months per €ct/kWh
$c =$	profile and disbalance costs
$p_b =$	basic energy price €ct/kWh

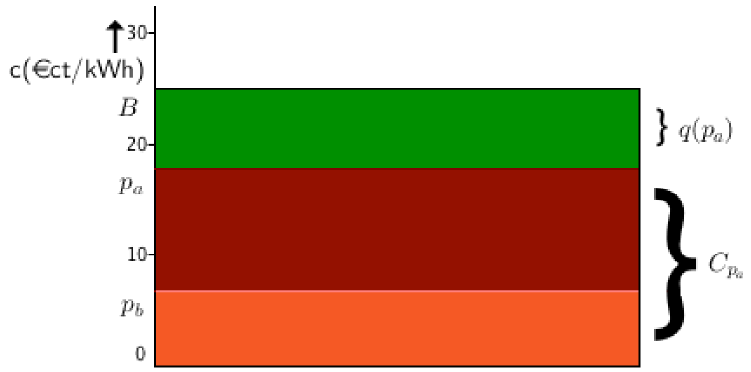

Figure 6: Amount of subsidy in SDE+

5.1 SDE+ abroad

To use the SDE regulation in other member states of the European Union (EU), there are some numbers that have to change to keep it fair for both the Dutch government and the owner of a renewable energy installation . The two bottlenecks are the basic price and the correction price. For the SDE regulation in the Netherlands the collected data like market price, sun hours and wind strength are detailed. In other member states of the EU the data are different and difficult to calculate accurately. The main problem for the market price is that each member state in the European Union has its own market prices. The key question that rises then is:

What is the most efficient market price to use in the SDE for an installation in another member state of the EU?

Simple options for the electricity market price:
1. p of Dutch market (APX)
2. p of host country
3. p as maximum of both market prices
4. p as minimum of both market prices
5. p as average of both marketprices

The first option is the most simple option, but not the most likely. This because the installation is built in another country where other costs exists. In the SDE regulation each case is individually specificed. If the installation is abroad, then the market price is probably not the exact same as the APX price as used in the whole SDE regulation by now. Taking the maximum or minimum is probably only useful, when the renewable energy can be sold as well as in the Netherlands as in the cooperation member state. Incorporating this option is way too difficult to bring into practice.
Taking the maximum market price results in the lowest subidy. This will be a benefit for the SDE regulation and so the Dutch government. On the contrary taking the minimum of the two market prices results in a high subidy. For each option the amount of subsidy is different, but in each case the basic price B is independed from the actual market price and is fixed at the beginning of each project. So the estimated subsidy in €ct per kWh is al-

ways the same. Only the amount of subsidy for new project changes, because it depends on the market price of the year in which the cooperation starts.

To incorporate a cooperation mechanisms within the SDE+ some options are already excluded. The Joint Support Scheme is seen as too difficult to implement. The ones that are left are Joint Project en statistical transfer.

5.2 Opening the Dutch SDE+ regulation

There are some problemes with opening de SDE+ for other MSs of the EU. The Dutch government wants to prevent as much as possible that a project abroad gets more subsidy than a similar project in the Netherlands. This problem stands in the basic price and correction price. Take for example high production costs with a low market price. This will result in a very high correctionprice. There are options to prevent this problem from happening. Three options down here:

option 1: Fixed correctionprice

This price can for example be the Dutch marketprice of the APX or the marketprice of the MS inwhich the installation stands. In this case C_{p_a} will be a set price (p_s).

option 2: Fixed correctionprice $\pm$ extra correction

This option gives a wider range with more possibillities. Using a fixed correctionprice and then compare this with the actual marketprice of the member state inwhich the installation is built. To prevent inequalities between installation in different MS's there is a margin in between the market price of MS_i can fluctuate without changing the fixed market price. In this case the extra correction is zero. When the marketprice of MS_i is outside the set margins around the fixed correction price, then there will be an extra correction. This extra correction is calculated with the deviation of the fixed price (p), the set price (p_s) and the margin (m).

$$C_{p_a} = \begin{cases} p_s & \text{if } D < 0, \\ p_s - D & \text{if } D > 0. \end{cases}$$

with $D = p - p_s - m$ the deviation outside the margins.

option 3: Correction price based on APX + extra correction

This options a quite similar to option 2, but we use now the APX marketprice in the Netherlands as 'fixed correctionprice'. But take in mind that this APX price changes every year. If there is choosen for the possibily of taking the APX price of one year as fixed price, than we're back in option 2.

Exclusions

For now already some simple exclusions can be made for cases that can not enter the SDE+. To bind the amount of subsidy that is paid by the Dutch government, a maximum amount money of all the subisdy toghether is set. And as explained earlier the SDE+ opens every year up first for the lowest cost productions of RE and at last the highest cost productions of RE. So also the SDE+ projects from abroad that will enter are limited.

Figure 8 gives a clear image of which RE projects are more likely to enter the SDE+ regulation. The red lines k and j represents RE project that are excluded for entering SDE+, because a C_{p_a} that is higher than the Dutch correction price NL_1 brings high risks with it for the Dutch government. The green lines h and i represent the amount of subsidy for RE projects that are considerd for SDE+. It is clear that project with a subsidy of amount $h = b - c$ ct€/kWh is more attractive to subsidize than a project with the amount of subsidy of $i = b - d$ ct€/kWh.

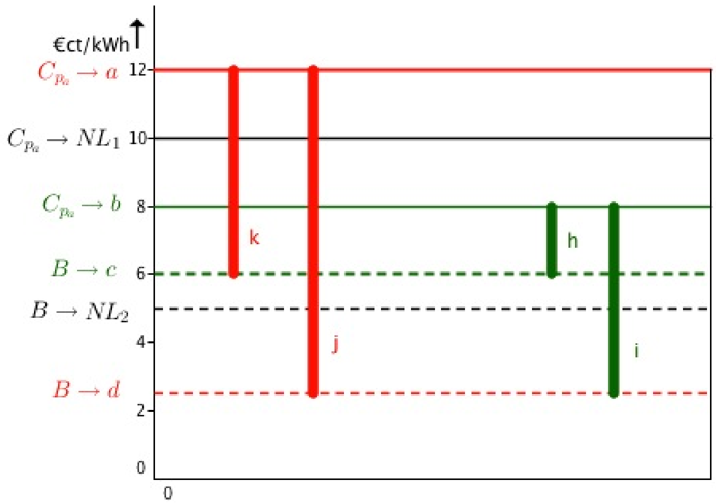

Figure 7: in- and exclude situations SDE+ abroad

As mentioned in the beginning of this section, using a fixed correction price for all projects with the same RE is an option. At the beginning of each RE project within the SDE+ the amount of subsidy is set for the whole cooperation between the Dutch government and the investor. Take into account that the market prices changes each day, so it can be that a project starts with the amount of subsidy h and after some time it changes into the amount of i. Then the investor is undersubsidized. This because the investor misses the amount of $c - d$ ct€/kWh. On the opposite a project is oversubsidized when it starts for instance with $C_{p_a} = i$ and changes into $C_{p_a} = h$. In the last case the amount of oversubsidizing is $c - d$ ct€/kWh.
A solution for these kind of problems that will occur with differentiation per country is a fixed $C - p_a$ for al project with the same RE like for instance the simple options that are explained in subsection 5.1. For so far there are no test cases known. So the results of the problems that will occur in a specified situation are not known yet. To prevent the opening of the SDE+ from failing exclusions has to be done.

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