benefit compared to the non-tradable situations. In this case, there are two effects. First, the firm obtains additional cost savings, and second, it emits less. However, as long as the overall number of permits is fixed, the total emission will not be reduced.

FIGURE 4 APP. HERE.

Given that developing new technology is costly, it is more likely that the new, cleaner technology is more profitable to develop under the ETS system than under the non-tradable situation. There is a caveat to this result. In the above example, the price in the market is assumed constant. But if more firms start adopting this new technology, the price in the market will fall, and the gain from the new technology will be smaller. In the limiting case, in which all firms would experience the same cost reduction from applying the new technology, the situation would be status quo and no additional gain would be experienced compared to the standard.

Finally, the inclusion of new sources that reduce the price in the market will lead to a decrease of the incentives to develop new technologies. This final point is illustrated in Figure 5. If the price in the market falls from p_1^{TPS} to p_2^{TPS}, the cost savings in the ETS compared to the non-tradable situation shrinks from area B to area C.

FIGURE 5 APP. HERE.

In conclusion, lower prices in the ETS provide fewer incentives for development and/or application of newer technologies. On the other hand, lower total compliance costs will make implementation of more stringent reduction targets less politically controversial.

5. A system for including farmers into an ETS

According to EEA (2009), EU farming contributed 9 % to the total EU-15 GHG emissions in 2007, whereas nitrous oxide accounted for 5 % and methane for 4 %. The contribution mostly comes from cattle (CH_4), and direct and indirect soil emission (N_2O), and a minor emission from swine (8% of the total emission from farming). The uncertainty attached to these measurements is considerable. The paper of Monni el al. (2007) in detail describes the great uncertainties related to measuring emissions of nitrous oxide and methane. According to their findings, great uncertainty is attached to N_2O emissions from agricultural soil in particular. Annual emission from EU 15 is app. 190 Tg CO_2e, but with great uncertainty, with a lower and upper bound of 95 % confidence interval of -100 to +1000% as a percentage relative to the mean. According to Monni et al. (2007), the reason for this is that emission is caused by complex biological processes with various changing parameters.

On the other hand, new research indicates that recent techniques for measurement, based on already existing data from both conventional and organic farmers, can reduce uncertainties to some extent (see Olesen, Fog and Svendsen, 2010). Moreover, emission inventories are calculated for any sector, including the farming industry. The IPCC (2006) provides a series of reduction factors that are used for this purpose. Applying such an approach to an individual farmer is the centre of the scheme we propose here.

In the following, we propose a system that can be used for including the farmers in the ETS, even though uncertainty and measurement problems exist.

As a starting point, farming contains a number of processes, like keeping animals, or producing crops. Each of these processes can be subdivided into activities like keeping different animals. Finally, for each such activities, different practices exists, like which fodder to give cows. The basic idea of this system is that instead of measuring the emission directly, we calculate the (average) change in emission from the baseline practice to the new practice. The whole idea of the system is that the authorities can in advance specify what practices should be accepted as valid reduction measures. (This could be motivated, e.g., by not including practices that are judged to generate uncertain results). We only want to illustrate our idea, therefore we here only focus on changes in practices and not on changes in activities of processes, but this be included without much complication.

Assume a number of farmers, $F^i, i = 1,2, \dots, n,$ are chosen to enter an ETS. (A criterion could be to only include farmers of a minimum emission level). We have to specify an allocation rule for the initial allocation of allowances to the farmers. Call the allocation rule $\alpha(a)$. As an example, a uniform allocation rule $\alpha(a,t)$ allocates to each farmer i at time t a number of allowances:

$$\alpha_t^i = a \cdot E_{t-1}^i$$

With $a \leq 1$, and where E_{t-1}^i is the calculated emission in (the end of) the previous period. If $a = 1$, there is no requirement of net reduction from the sector in this period, while for any $a < 1$, there is a requirement of net reduction from the sector in this period.

Now let us look at how to calculate emissions from activities and practices. Let a number of activities be $A_j, j = 1,2, \dots, J$. For each such activity, there is a number of practices, indexed by $k = 1,2, \dots, K_j$. Each activity practice pair has an emission factor per unit of measurement (E.g., one cow fed with fat food has an emission factor of β_{cff}, while the emission factor of conventional food is β_{ccf}). If a farmer switches from conventional to fat food, the emission reduction per cow per year is given by: $\beta_{ccf} - \beta_{cff}$. More generally, we call the units U_j^i (in the above example a cow) and activity practice pair the emission factor for β_{jk}.

Let us now turn attention to reduction projects of farmer i. Such a reduction project in our setting is a change in practice from a baseline (BL) practice to a new practice. We write the change in emission per unit activity as $\Delta_k \beta_{kj} = \beta_{kj}^{BL} - \beta_{kj}$. We introduce time as t to indicate that permits are valid in a limited period of time. To simplify, assume that farmer i total has $l = 1,2, \dots L^i$ reduction projects. [1]Reduction from project l for farmer i is given by $R_t^{li} = \Delta_{kt} \beta_{kj} \cdot U_{kj}$, i.e.to make this model work, we need to specify all the β's, as this also defines the p_j's and all the U_j's. (Here, we ignore the case that U_j^i could also be changed. But this is easily included into the model.). Finally, total reduction is given by $R_t^i = \sum_{l=1}^{L^i} R_t^{li}$.

How many allowances must farmer i hand in at the end of the period? This is calculated in the following way, where $A_t^i(\text{hand in})$ means the number of allowances that farmer i must hand in to the authorities in the end of period t:

[1] So if a farmer has two activities and for the first changes two practices and for the second 1, $l = 3$.

$$A_t^i(\text{hand in}) = E_t^i - R_t^i$$

So for each type of activity, j, we calculate the reduction due to changed practices (there could be more than one practice for an activity, or for subsets of this activity). Subsequently, we sum over the reductions for each activity to obtain the total reduction. This sum is then subtracted from the emission level of this source at the beginning of the period. This provides the number of allowances that the farmer must hand in. If this sum is lower than the initial allocation, the source can sell from the remaining allowances. If the sum is larger than the initial allocation (which is possible either when $a < 1$ and no reduction undertaken, of $a = 1$, but emission increased), this source must buy additional allowances. In appendix 1, we present an example of how this system works.

TABLE 2 APP. HERE.

Fødevareministeriet (2008) states that the total potential for reducing emissions from farming in Denmark is estimated to be 3851 MtCO2e per year, which amounts to 31 % of the emission from agriculture and 6 % of the total emission (year 2007). However, incentives to choose new practices depend on (net) costs of these new practices and the P^{TPS}. In Table 2, we show the most promising practices in terms of size and costs.

There are, however, even more effective ways of reducing emission, which is not included in Table 2. According to Fødevareministeriet (2008) and Chatskikh et al. (2008), reduced tillage (and direct drilling), which are methods that reduce labour and energy efforts, show a great CO_2e reduction potential. The reductions can mainly be attributed to reduced energy uses, increased storage of CO_2 in the soil and net changes in the emission of nitrous oxide. The studies conclude that the total emissions reduction is app. 370 kg CO_2/ha, with approximately 90 % stemming from storage. Other studies are, however, not so optimistic with respect to the potential of carbon sequestration from reduced tillage. According to Baker et al (2007), the problem is that most studies only examine samples to a depth of 30 cm or less, while the few samples providing data for larger depth show that conservation tillage actually results in loss of carbon compared to traditional tillage. (See also Wang et al. (2004) for similar results). These authors conclude that other management practices may ultimately be more fruitful for carbon storage.

This again underlines the strength of our proposed system. As long as too much uncertainty is attached to a method, it should remain outside the system, but it sends signals where to improve research. E.g., VandenByggart et al (2003) analyze data for Canada finding correlation between decreased background levels of soil organic (SOC) and the potential to store SOC when non tillage is adapted. From this they conclude that management like plowing green manures into the soil, and applying N and organic fertilizers were the practices that tended to show the most consistent increases in SOC storage. According to Dalal et al. plowing methods also affect the release of nitrous oxide: For manure management, the most effective practice is the early application and immediate incorporation of manure into soil to reduce direct N_2O emissions as well as secondary emissions from deposition of ammonia volatilised from manure. See also Iqbal (1992) for an earlier study of the connection between denitrification and the soil contend of carbon and Dorland and Beauchamp (1991) for a study of the linkage of denitrification and ammonification. These examples show how new research gives increased knowledge that can be applied for new methods to enter the system.

Our approach will most likely reduce such costs significantly, since it proposes a list of acceptable methods and associated factors of reduction which are then standard to all farmers. This means a system without significant certification and verification costs. The list of acceptable methods could e.g. be proposed and delivered by the EU. Moreover, the system would make the allowances earned in this sector a valid and reliable ‘currency’ in the EU ETS.

At present (May 2010), the price of allowances is app. 13€/tonnes CO_2. If comparing this price with the reduction costs in Table 2, such a price will, all else equal, only imply minor reductions from the farming sector. There are, however, two reasons to expect that this will underestimate the future potential for reductions in the farming sector, if it is included in the EU ETS.

The first reason is that in an ETS, as already stressed in the previous section, the participants have incentives to find new and/or cheaper ways of implementing these measures, implying that costs of the above measures fall. The second reason is that if the third phase will be implemented, the allowance price is likely to increase once the number of allowances is reduced.

Finally, we proposed a scheme that may be considered a project-based approach, in which the regulator in advance makes a list over farming practices that can be used as valid reduction measures in the EU ETS system. This brings about the question of which practices to include? One reasonable criterion would be to only include practices in which the uncertainty is minor. The uncertainty here could relate to measurement uncertainty or simply lack of understanding of the underlying biological/chemical processes. As new research reduces such types of uncertainty or new methods that contain less uncertainty are developed, the list of acceptable practices can be expanded.

6. Conclusion

The EU is facing a great challenge under the Kyoto Protocol in its ambitious efforts to improve climate change initiatives and achieve a 20 % GHG reduction from 1990 to 2020. Crucially, the participation of farmers could be one extra important tool for the European Union to succeed. Overall, the inclusion of both conventional and organic farmers in the EU ETS offers a solution which meets the interests of farmers and the EU as a whole. If the challenge of incorporating agriculture in the EU ETS can be addressed adequately, indeed, the role of farmers in climate policy may become a hot issue during future climate meetings. As a result, the US would probably be much more likely to rejoin the Kyoto agreement (or rather the post-Kyoto agreement), thereby clearing the road for the participation of China and India as well. Until now, the US has strongly advocated land-use practices as 'the missing link' in past climate negotiations. Finally, farmers may avoid future production losses as climate change evidently may have a significant economic impact on agriculture in near future.

How to develop a system for including farmers in the EU ETS? This research question was motivated an empirical puzzle, namely that farmers may harvest private net gains from participating. Recent surveys clearly indicate that farmers face relatively low marginal reduction costs. Low hanging fruits exist both within conventional farming and, perhaps, organic farming in particular. Farmers as a group may gain significant benefits from GHG trade. Furthermore, the option of grandfathering rather than auctioning would be the first step to attract farmers to the system.

We argued that there were also other strong economic reasons to develop a system for farmers' participation in the EU ETS. First, the market consequences in terms of the effect on permit price and technology were overall positive. Regarding the effects on the price of allowances, it was not likely that the inclusion of the farming industry would have a significant influence on the price because of its relatively small size compared to the overall emissions. It would, however, imply a larger volume of trading, resulting in cost-efficiency gains. Incentives to development and/or implementation of new and cleaner technologies were, however, also largely affected by expectations of future allowance prices. An increase in the allowance price was to be expected in the future, which would generally spur incentives for technology improvements. This was also likely for the farming industry, making more and more new practices attractive. Note that being in an ETS provides continuous incentives to make new practices cheaper or more effective, even if the price of allowances remains constant (compared to ordinary CAC regulation). Therefore, the estimates of present costs of reductions for the various measures (like the one presented in table 2) typically exaggerated costs for applying these measures in the future.

Based on these economic arguments, we proposed a project-based system that makes it possible to overcome some of the potential shortcomings from including farmers into the EU ETS, which have been put forward. First and foremost, farmers would increase measurement problems and uncertainty significantly as emissions are a non-point source. The project-based framing makes the system resemble a joint implementation arrangement. A project in this system is an approved way of reducing emissions, either by introducing a new, less polluting practice or by reducing the polluting activity. In this system it is possible to control the uncertainty by only including the least uncertain elements. As new and better information is available, new practices can be included, such that the system also is flexible. Finally, it still provides the farmers to invest in GHG reducing activities. When doing so, farmers will receive GHG permits corresponding to the amount of reduction which can be stored for later use or sold in the EU ETS. In this way, the farmers may be included, without increasing the uncertainty in the EU ETS significantly.

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APPENDIX 1

Example (numbers are totally random).

Consider a situation with three farmers and two activities. Activity 1 has two possible practices, while activity 2 has three practices. So far, all the farmers use the practice that has the highest emission factors.

Farmer	U_1	U_2
F_1	30	40
F_2	20	50
F_3	10	70

β_{11} (Baseline)	0.7
β_{12}	0.5
β_{21} (Baseline)	0.4
β_{22}	0.5
β_{23}	0.2

Assume that F_1 uses β_{12} instead of β_{11} and that F_2 uses β_{23} instead of β_{21}. F_3 does not change practice over the period.

Calculate the initial emissions:

$$E_0^1 = 30 \cdot 0.7 + 40 \cdot 0.4 = 37$$
$$E_0^2 = 20 \cdot 0.7 + 50 \cdot 0.4 = 34$$
$$E_0^3 = 10 \cdot 0.7 + 70 \cdot 0.4 = 35$$

sum = 106

Calculation of net reductions:

$$R_0^1(\beta_{12}) = (0.7 - 0.5) \cdot 30 = 6$$
$$R_0^2(-) = 0$$
$$R_0^3(\beta_{23}) = (0.4 - 0.2) \cdot 70 = 14$$

sum = 20

Let $\alpha = 0.9$

The first period allocation of allowances is given by:

$$A_0^1 = \alpha \cdot E_0^1 = 0.9 \cdot 37 = 33.3$$
$$A_0^2 = \alpha \cdot E_0^2 = 0.9 \cdot 34 = 30.6$$
$$A_0^3 = \alpha \cdot E_0^3 = 0.9 \cdot 35 = 31.5$$

sum = 95.4

The number of allowances to hand in and the surplus allowances:

$A^1(\text{hand in}) = E_0^1 - R_0^1 = 37 - 6 = 31$

Surplus allowances for farmer 1: $A_0^1 - A^1(\text{hand in}) = 33.3 - 31 = 2.3$

$A^2(\text{hand in}) = E_0^2 - R_0^2 = 34$

Surplus allowances for farmer 2: $A_0^2 - A^2(\text{hand in}) = 30.6 - 34 = -3.4$

$A^3(\text{hand in}) = E_0^3 - R_0^3 = 37 - 14 = 23$

Surplus allowances for farmer 3: $A_0^3 - A^3(\text{hand in}) = 31.5 - 23 = 8.5$

The total surplus of allowances is: 7.5

Figure 1: *Marginal reduction curve*

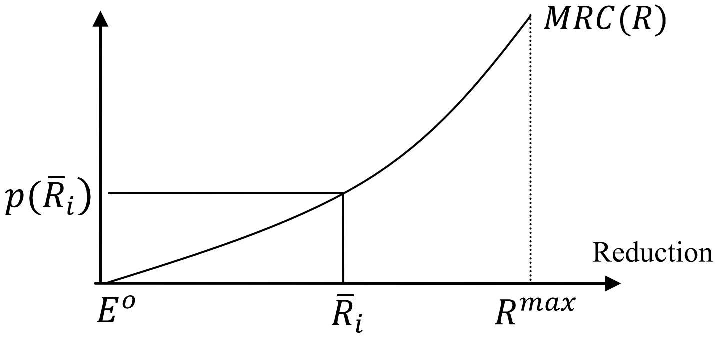

Figure 2: *Individual firms' demand and supply for permits*

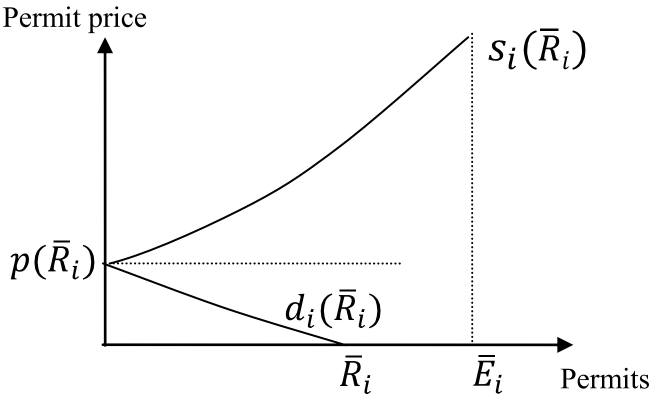

Figure 3*: The market for permits*

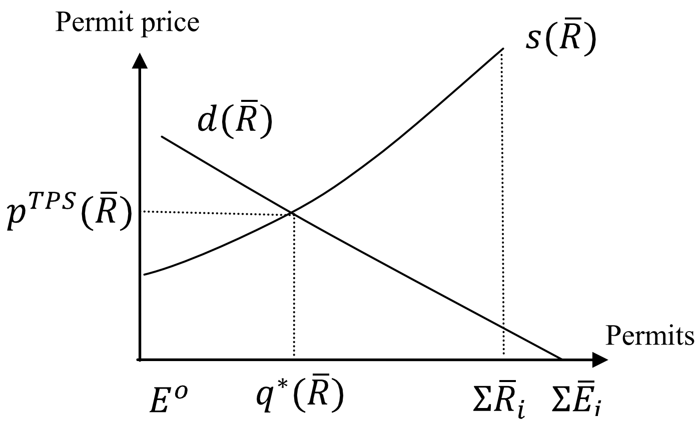

Figure 4*: A selling firm*

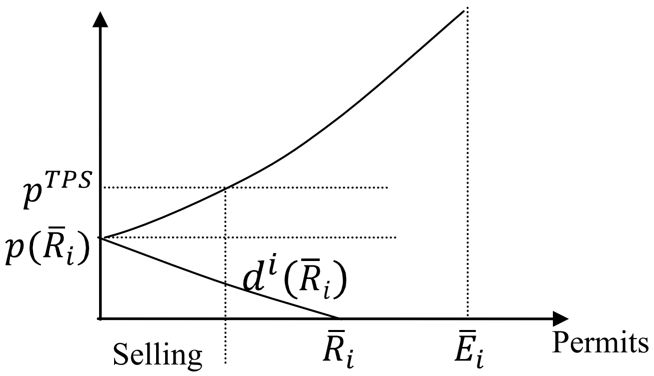

Figure 5: *Cost reduction of new technology: Comparing ETS with a standard.*

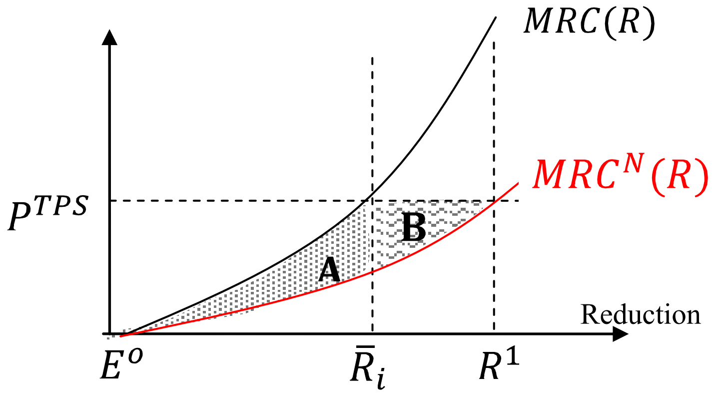

Figure 6: *Lowering of price in the ETS reduces incentives to develop new technology*

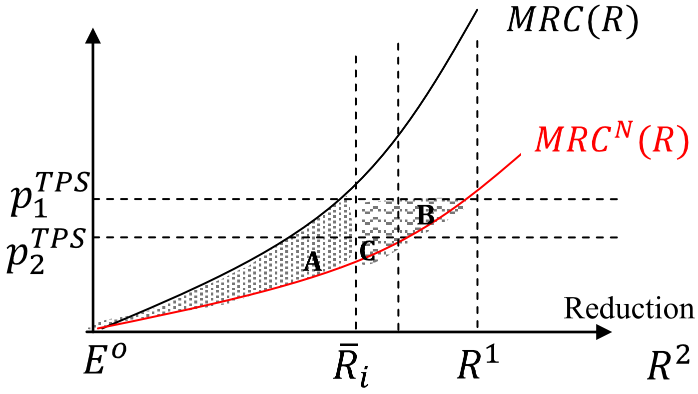

Table 1: GHG emissions from different sectors in the EU-27, 2007.

Sector	%
1. Public Electricity and Heat Production	27.8
2. Transport	19.5
3. Manufacturing Industries and Construction	12.7
4. Agriculture	9.2
4. Industrial Processes	8.5
6. Residential	8.5
7. Commercial/Institutional	3.3
8. Waste	2.8
9. Petroleum Refining	2.7
10. Fugitive Emissions from Fuels	1.7
1.1. Agriculture/Forestry/Fisheries	1.5
12. Manufacture of Solid Fuels and Other Energy Industries	1.4
13. Solvent and Other Product Use	0.2
14. Other (Not elsewhere specified)	0.2
Total	100.0

Source: EEA (2010)

Table 2: Potential reduction measures, their size and costs

Type of measure	**Reduction potential**[1] (Denmark)	**Reduction cost**[2] **(**€/tonnes CO_2e)
Bioenergy		
Straw for energy production	298	15
Manure management	807	90
Willow chips	1270	Sandy soil: 55 Clay soil: 92
Energy maize	531	179
Domestic animals		
Adding fat in cattle feed above standard	298	43
Nitrification inhibitor	272	191
Cropland management		
Summer catch crops	280	n.a.
Set-aside of agricultural area on lowland	295	29
Grassland	247	911
Agroforestry	321	911

Source: Danish ministry of Food, Farming and Fisheries (Fødevareministeriet, 2008 [Our translation]). Note: Numbers do not include any reduction of domestic animals since it is assumed that a reduction in one country region will increase the number of animals elsewhere.
[1] Estimated potential for reduction of GHG from farming until 2020 (1000 ton CO2e per year).
[2] Numbers are costs to the farmers of implementing the measure. C-storage in soil is not included.