Aalto University
School of Science
Degree programme in Engineering Physics and Mathematics

# The effect of $CO_2$ taxes in overall energy production cost using electricity capacity expansion model

Bachelor's Thesis
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Tiivistelmä:

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# Contents

# 1 Introduction

Energy production methods have changed during the last decades and will be changing more in the future. The main reason for this are the CO2 emissions and other greenhouse gas emissions that are to be cut down due to their negative effects on the environment. New renewable energy sources such as wind power and solar power (later PV) have some properties not familiar to previous energy production. The production output of legacy sources such as coal are typically kept constant in order to maximize their cost efficiency. With the renewables the output isn't usually constant nor exactly predictable. Therefore more advanced methods are required to allow deploying these systems in more greater part of total energy production

Energy production modeling is especially important for decision making as the models are rather robust and approximate than exact and usable for i.e. daily usage planning. However, these models allow us to simulate scenarios that are helpful in decision making.

The model used in this study is a modified energy production capacity expansion model (EPCPM). The model allows for determining current situation and it optimizes the possible expansions required to meet the requirements. The optimization is based on minimizing the total price tag of the system.

The scope of this study are the carbon emission tax levels and their effect on the total share of renewable energy sources. This investigation allows possibilities for more detailed analysis on whether high or low tax rates actually impact societies and should the international carbon emission limitations follow tax based penalty system.

# 2 Theory

# 3 Methodology

## 3.1 Basic Indices and Sets

| Index or Set name | Type | Description |
|---|---|---|
| $T$ | Set | Set of Production Technologies |
| $S$ | Set | Set of Storage |
| $H$ | Set | Set of Hours |
| $C^t$ | Set | Subset of Technologies emitting carbon emissions |
| $t$ | Index | Technology $\in T$ |
| $h$ | Index | Time index $\in H$ |

## 3.2 Parameters

Parameters

| Parameter | Type | Unit | Description |
|---|---|---|---|
| $p_t^0$ | Set | MW | Initial capacity of $t \in T$ |
| $\hat{p}_t$ | Set | MW | Maximum capacity of $t \in T$ |
| $\rho_{t,h}$ | List | | Capacity factor of each $t$ at each $h$ |
| $r_t^-$ | List | | Ramp down maximum of $t \in T$ |
| $r_t^+$ | List | | Ramp up maximum of $t \in T$ |
| $Bc_s^+$ | List | MW | Maximum $\Delta b_{s,h}^+$ of $s \in S$ |
| $Bc_s^-$ | List | MW | Maximum $\Delta b_{s,h}^-$ of $s \in S$ |
| $\bar{b}_s^0$ | List | MW | Initial capacity of $s \in S$ |
| $\hat{b}_s$ | List | MW | Maximum capacity of $s \in S$ |
| $Vc_t$ | List | €/MWh | Variable cost parameter for $t \in T$ |
| $Fc_t$ | List | €/MWh | Fixed cost parameter for $t \in T$ |
| $\xi_t$ | List | MWh/ton | Production factor for $t \in C^t$ |
| $\tau$ | Double | €/ton | Carbon tax |
| $\bar{d}_h$ | List | MW | Demand at $h \in H$ |
| $i_t$ | List | €/MW | Investment cost for $t \in T$ |
| $i_s$ | Double | €/MW | Investment cost for $s \in S$ |
| $y_t$ | List | a | Expected life time of $t \in T$ |
| $y_s$ | List | a | Expected life time of $s \in S$ |

## 3.3 Decision variables

Variables

| Parameter | Type | Unit | Description |
|---|---|---|---|
| $b^{+}_{s,h}$ | List | MW | Charge of $s \in S$ at $h \in H$ |
| $b^{-}_{s,h}$ | List | MW | Discharge of $s \in S$ at $h \in H$ |
| $b_{s,h}$ | List | MWh | Energy level of $s \in S$ at $h \in H$ |
| $\bar{b_s}$ | List | MW | Additional capacity of $s \in S$ |
| $d_h$ | List | MW | Satisfied demand at $h \in H$ |
| $pt, h$ | List | MW | Generation of energy of $t \in T$ at $h \in H$ |
| $\bar{p_t}$ | List | MW | Additional capacity of $t \in T$ |

## 3.4 Objective function

$$\min_x \sum_t \sum_h Vc_t \cdot p_{t,h} + Fc_t \cdot \bar{p_{t,h}} \tag{1}$$

$$+ \sum_t sc \cdot (\bar{d_t} - d_t) \tag{2}$$

$$+ \sum_t \frac{i_t}{y_t} \cdot \bar{p_t} \tag{3}$$

$$+ \sum_s \frac{i_s}{y_s} \cdot \bar{p_s} \tag{4}$$

$$+ \sum_{C^t} \sum_t \frac{p_{t,h} \cdot \tau}{\xi_t} \tag{5}$$

## 3.5 Conditions

$$0 \leq d_h \qquad ,\forall h \in H \tag{6}$$

$$0 \leq \bar{p_t} \leq \hat{p_t} \qquad ,\forall t \in T \tag{7}$$

$$0 \leq \bar{b_s} \leq \hat{b_s} \qquad ,\forall s \in S \tag{8}$$

$$0 \leq \bar{b^{+}_{s,h}} \leq \hat{Bc^{+}_s} \qquad ,\forall s \in S, h \in H \tag{9}$$

$$0 \leq \bar{b^{-}_{s,h}} \leq \hat{Bc^{-}_s} \qquad ,\forall s \in S, h \in H \tag{10}$$

$$\sum_t p_{t,h} + \sum_s (\bar{b^{-}_s} - \bar{b^{+}_s}) = d_h \qquad ,\forall h \in H \tag{11}$$

$$0 \leq p_{t,h} \leq \rho_{t,h} \cdot (\bar{p^0_t} + \bar{p_t}) \qquad ,\forall t \in T, h \in H \tag{12}$$

$$p_{t,h} - p_{t,h-1} \geq -r^{-}_t \cdot (\bar{p^0_t} + \bar{p_t}) \qquad ,\forall t \in T, h \in H \backslash h_1 \tag{13}$$

$$p_{t,h} - p_{t,h-1} \leq r^{+}_t \cdot (\bar{p^0_t} + \bar{p_t}) \qquad ,\forall t \in T, h \in H \backslash h_1 \tag{14}$$

# 4 Results

# 5 Conclusion

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# References

# A Appendix

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