# Prices vs. percentages: Use of tradable green certificates as an instrument of greenhouse gas mitigation

Arild Heimvik and Eirik S. Amundsen

# Introduction/Motivation

- Tradable green certificate schemes (TGC) primarily used for stimulating construction of new renewable generation capacity
- However, main objective is to replace fossil-based electricity generation with emission free technologies

- ***How suited is a TGC scheme in achieving a specific target path of emission reductions?***

# What we do in the paper

- Assume a regulator that wants to achieve a target path of emission reductions in the electricity sector

- Study the performance of TGC scheme in an analytical model w.r.t.
  - Path of optimal emission reductions
  - Investments in new green generation capacity
  - Costs (Social surplus)

  - Compare outcomes with an emission fee and a subsidy

  - Theoretical results are illustrated with a numerical model

# Model

- $p_t$: Price of electricity at date t, net of distribution costs
- $q_t$: Wholesale price if electricity at date t
- $s_t$: Price of green certificates at date t
- $x_t$: Consumption of electricity at date t
- $y_t$: Generation of elctricity from non − renewable sources at date t
- $\bar{z}_t$: Generation capacity of renewable electricity at date t
- $k_t$: Physical investment in new generation capacity of renewable electricity at date t
- $\alpha_t$: Target share of green electricity out of total electricity consumption at date t
- $r$: Social discount rate
- $\rho$: Rate of technological change
- $\kappa$: Depreciation rate of green generation capacity
- $T$: Termination date of problem considered

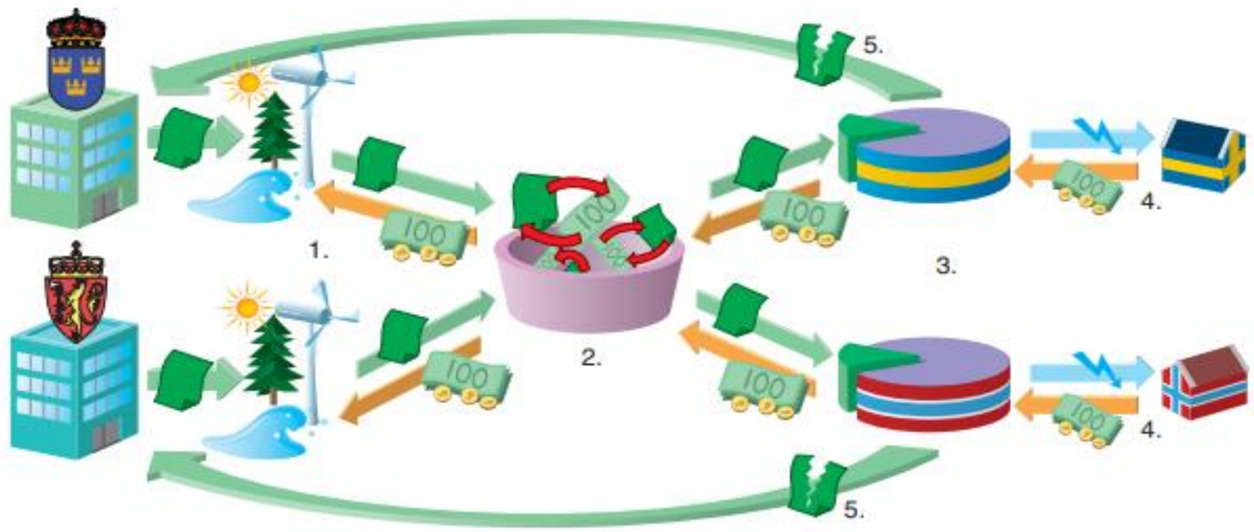
# Model – cont.

- $p(x_t)$: Price function for electricity, with $\frac{\partial p_t}{\partial x_t} < 0$
- $c(y_t)$: Cost function for production of black electricity , with $\frac{\partial c}{\partial y_t} > 0$ and $\frac{\partial^2 c}{\partial {y_t}^2} \geq 0$
- $g(\bar{z}_t)e^{-\rho t}$: Cost function for green generation capacity with $g'(\bar{z}_t) > 0$ and $g''(\bar{z}_t) \geq 0$
- $k_t$: Investment in renewable generation capacity in period t, with. $k_t \geq 0$
- $\dot{\bar{z}}_t = k_t - \kappa\bar{z}_t$
- $x_t = y_t + \bar{z}_t$
- $\bar{z}_t = \alpha_t x_t$
- $y_t = (1 - \alpha_t)x_t$
- $\bar{y}_t = y_0 e^{-\chi t}$: Target path, defined by the regulator

# New in the paper

- Study the behavior of a TGC scheme over time
- Develop an optimal path for the percentage requirement
- Analyze two different versions of the percentage requirement ($\alpha$) in a TGC scheme
- Analysis of optimal instruments in a dynamic model

# The Norwegian - Swedish Tradable green certificates system (TGC)




**How the electricity certificate market works:**

(1) The energy producers receive one electricity certificate for each megawatt hour (MWh) of renewable energy produced, over a maximum 15 years.

(2) The electricity certificates are sold in a market where prices are determined by supply and demand. In this way, the producers receive extra income in addition to the energy price.

(3) Demand for electricity certificates arises in that energy suppliers and certain electricity customers are obligated by law to buy electricity certificates corresponding to a certain proportion (quota) of their calculation-relevant electricity consumption.

(4) The electricity end users pay for the development of renewable energy production because the cost of the electricity certificates is included in electricity bills.

(5) Every year, the market participants with quota obligations must cancel electricity certificates in order to fulfil their quota obligation.

# Socially optimal solution to problem

- $\boldsymbol{p_t = [(r+\rho+\kappa)g(\bar{z}_t) + \kappa\bar{z}_t g'(\bar{z}_t)]e^{-\rho t}}$
- $\frac{\partial H_t}{\partial y_t} = [p_t - c'(\bar{y}_t)]e^{-rt} - \omega_t = 0$
- $\frac{\partial H_t}{\partial k_t} = -[g(\bar{z}_t)e^{-\rho t}]e^{-rt} + \beta_t = 0$
- $\frac{\partial H_t}{\partial \bar{z}_t} = [p_t - g'(\bar{z}_t)e^{-\rho t}k_t]e^{-rt} - \beta_t\kappa = -\dot{\beta}_t$

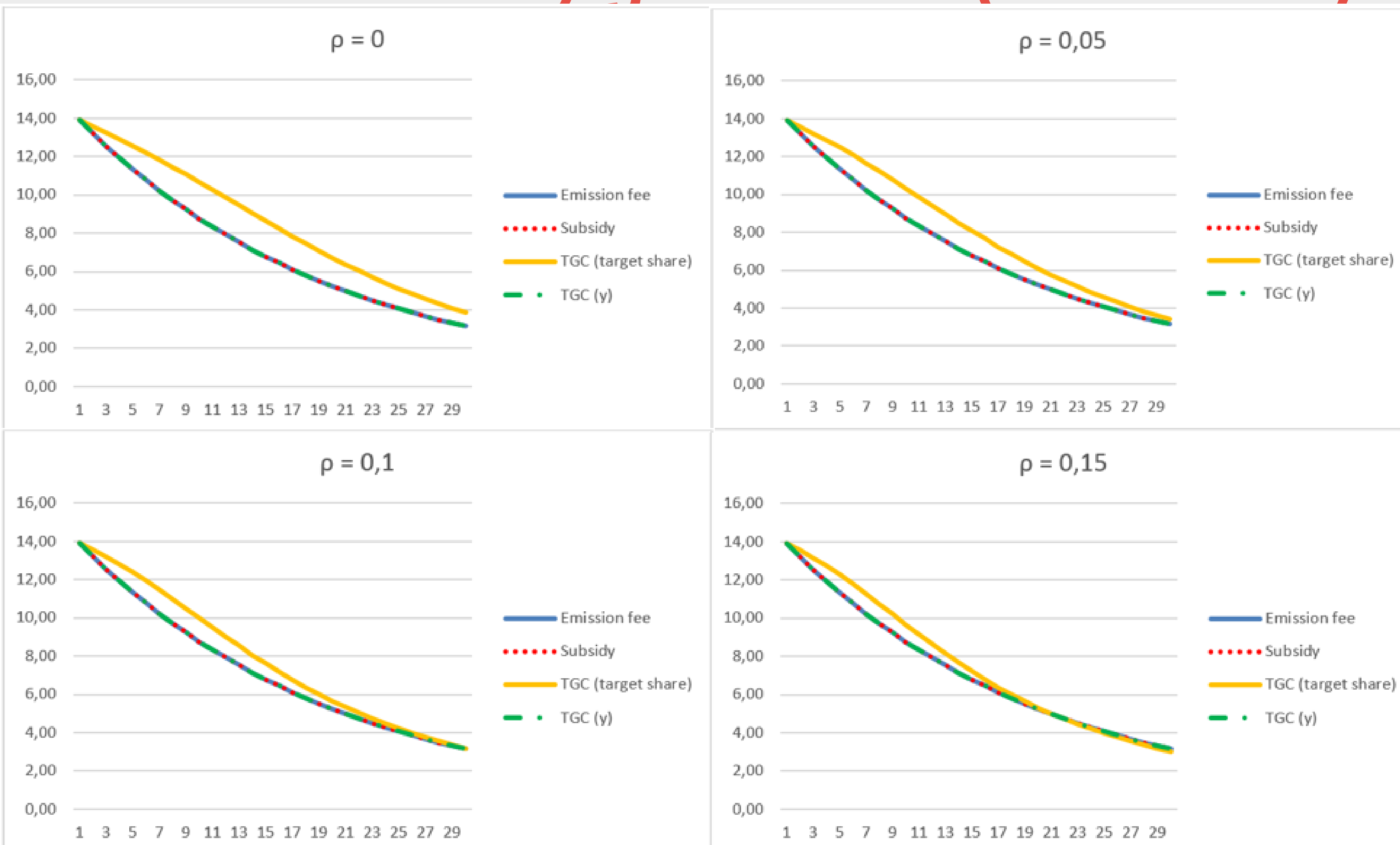
# TGC scheme -1/2 α(target share)

- Use the percentage requirement to displace generation of black electricity ($y_t$) with generation of green electricity ($\bar{z}_t$)
- Calculation of percentage requirement: $\alpha_t = \frac{\bar{z}_t}{x_t}$
- Previous findings: Not clear-cut effect from using TGC, but $\boldsymbol{\alpha} \uparrow \rightarrow \boldsymbol{y} \downarrow$
- Our theoretical results confirm this, but results are indeterminate when green technology becomes cheaper
- ***With α(target share):***
  - Target path of emission reductions is not achieved
  - Sub-optimal investment in new green generation capacity

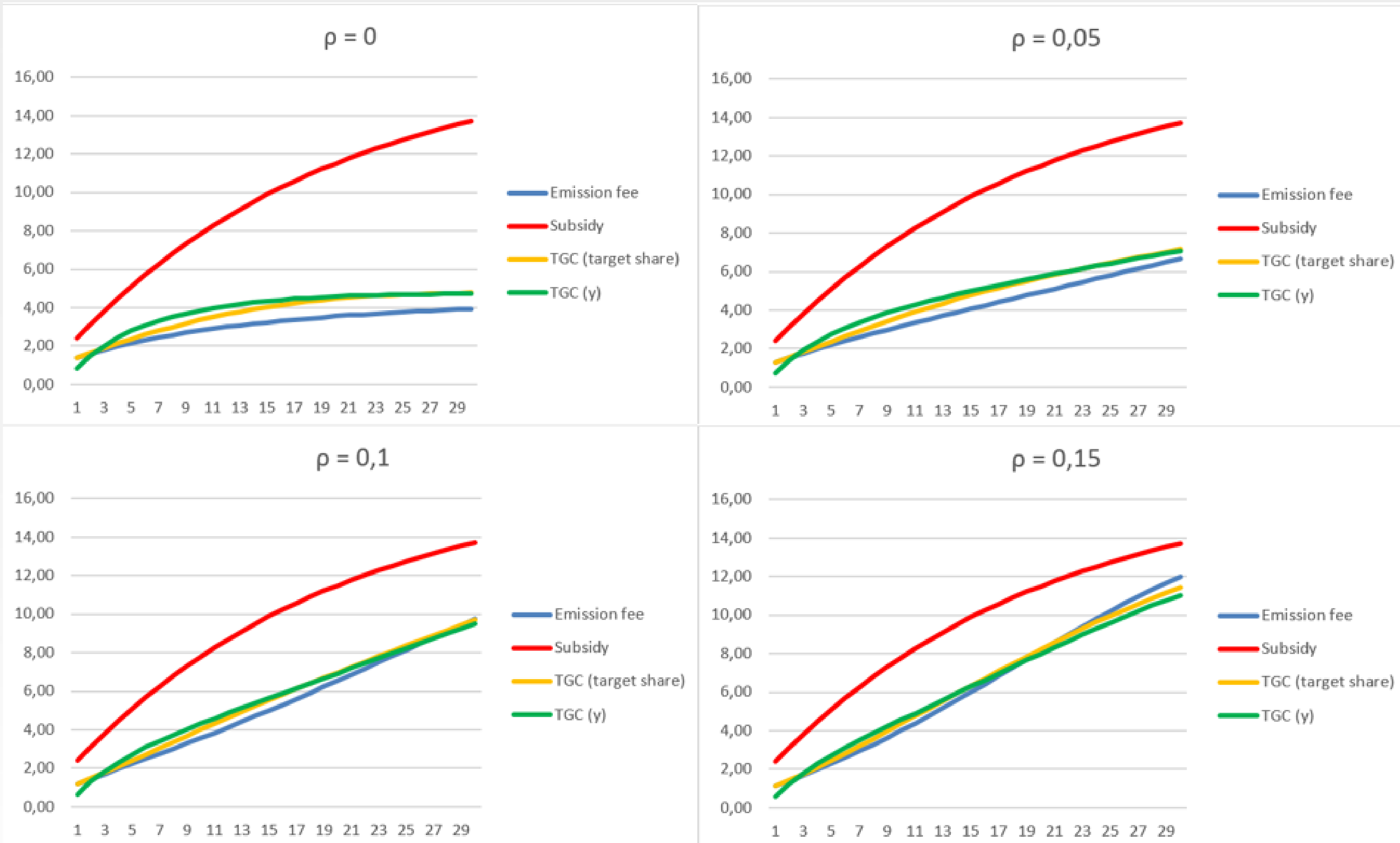
# TGC scheme 2/2 α(y)

- Devise alternative version of α to achieve target set by regulator
- α(y): Calculated to ensure that that the target path of emission reductions is met explicitly (derived implicitly)
- ***With α(y):***
  - Target path of emission reductions is achieved
  - Sub-optimal investment in new green generation capacity

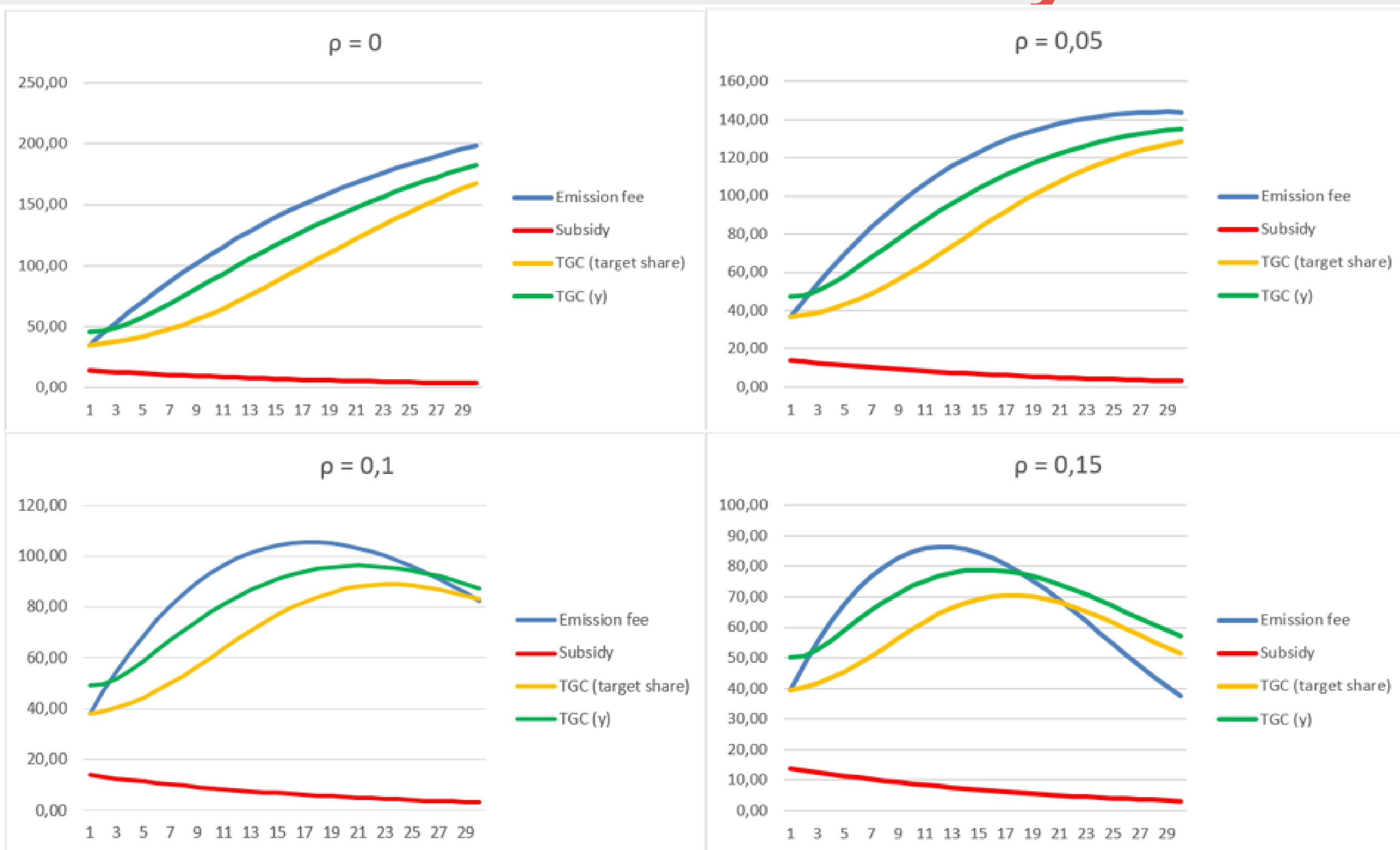
# Black electricity generation (emissions)



# Green generation capacity

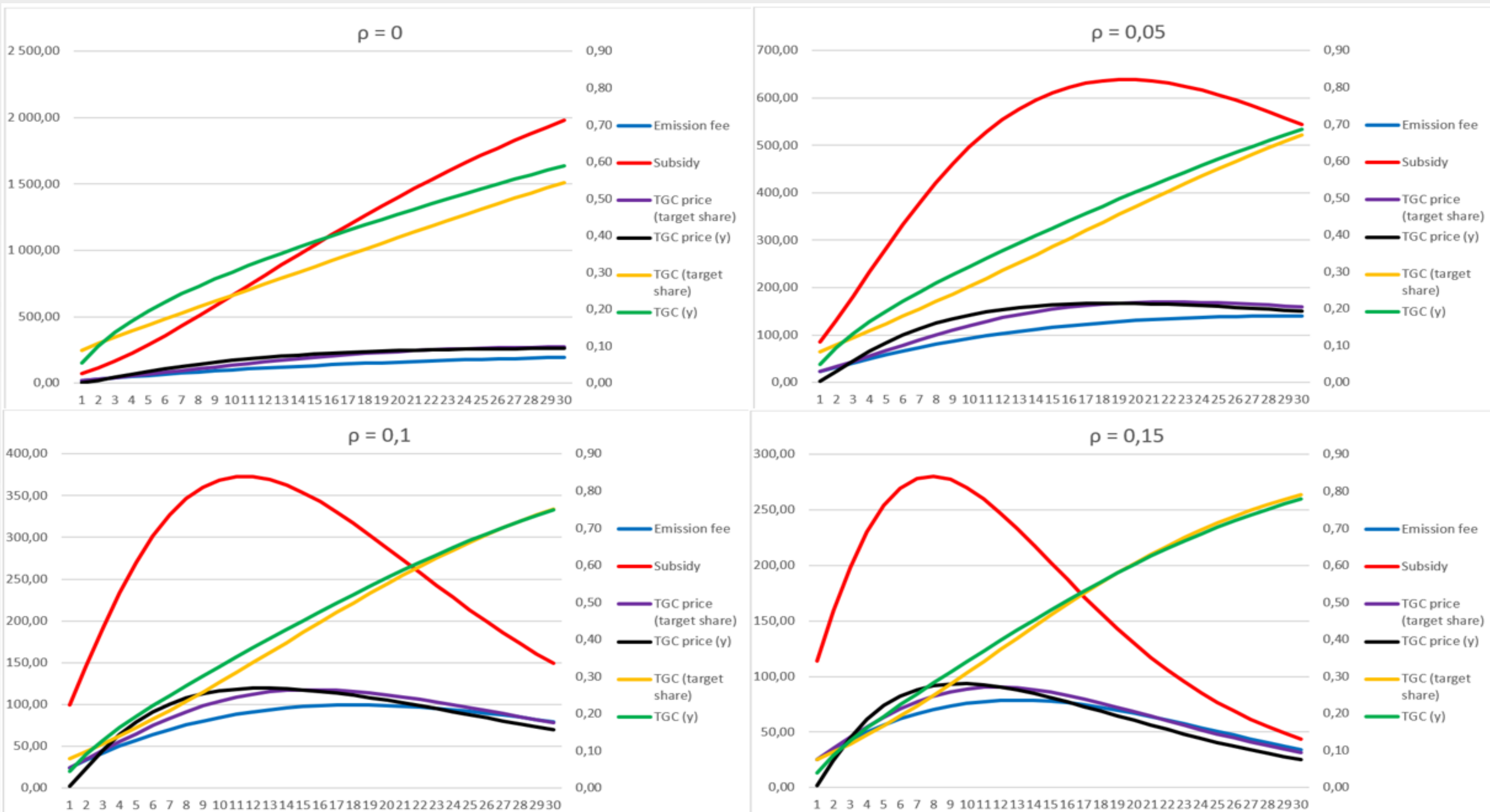


# Price of electricity



# Path of emission fee, subsidy, both TGC prices and percentage requirements





# Results

- We derive two versions of α with a TGC scheme
  1) TGC(target share)
     - Decrease of emissions – but not in accordance with target path
     - Sub-optimal investments in new green generation capacity
  2) TGC (y)
     - Achieves target path of emission reductions
     - Sub-optimal investments in new green generation capacity
- $P^{TGC(target\ share)} < P^{TGC(y)}$
- Emission fee – optimal instrument
- Subsidy – achieves target path, but results in overinvestment

- Effect of α on investments and price of electricity with TGC, compared to social optimum

- $W_{emission\ fee} > W_{TGC(y)} > W_{TGC(target\ share)} > W_{subsidy}$

- TGC scheme more politically feasible instrument?

UNIVERSITETET I BERGEN