Introduction
Radiative forcing, better known as the Greenhouse Effect, is probably the major 21st century environmental problem. Its probable cause is the anthropogenic emission of greenhouse gases, especially CO$_2$. The Kyoto agreement enforces considerable reductions of the GHG emissions in 2010, with 6 to 8% of the 1990 level. Still these reductions are not sufficient to keep climate change within manageable levels.

After 2010 the necessary emission reductions require major technological changes. Improvement of existing processes is not sufficient. This means that society has to enter a technological transition of probably several decennia. Governments will play a major role, as they have to provide consumers and companies with the incentives to make the required changes. Financial incentives, such as a CO$_2$ tax, give CO$_2$ emissions a financial value. By making decisions that reduce their emissions, companies and consumers can minimize their tax costs. A gradual introduction will allow society to adapt.

Many decisions, especially of companies, have a long-term influence. The influence period is often longer than the period considered in the decision making, the foresight period. This may cause companies to take decisions in the beginning of the transition to prove to be disadvantageous in the longer term. In addition, at the start of the transition companies have a heritage of past decisions. The starting positions and initial decisions may prove decisive for the future developments. A common name for this influence of past decisions on future developments is path-dependency.

The primary steel industry combines a large sensitivity to CO$_2$ policies with a strong likelihood of path-dependency. In the steel industry, path-dependency is due to the long lifetimes and high capital costs of processes, combined with the extensive possibilities to upgrade existing processes against relatively lower costs. The primary steel industry makes an excellent case for the investigation of the influence of path-dependency on the transition process. The steel industry allows the modelling of the transition process including the factors that give rise to path-dependency. This thesis aims at identification and quantification of the role of path-dependency in the primary steel industry, especially in case of policy-induced shifts to other production processes.

Identification and isolation of the influence of path-dependency requires knowledge on the influence of all kinds of factors that play a role in the choice of technologies. Several analyses identify the influence of individual factors, and provide references for the model results. Chapter 2 describes the data on steel production technologies and selects relevant steel production routes. Chapter 3 describes the recent history of the European steel industry. Both chapters provide the basis for the following analyses. The analyses of chapter 4 isolate the influence of various factors on the chances of the included production routes and on the timing of technology shifts. Chapter 5 describes the SimCo model designed to simulate the development of iron and steel companies. Chapter 6 describes the SimCo results. Chapter 7 compares the SimCo results with references in order to isolate the influence of path-dependency. Finally, chapter 8 discusses the included analysis and draws conclusions their results.
Technological inventory
The research for new technologies for iron and steel production has resulted in various new processes. Application of these processes generally concerns niche-applications in developing countries. Gradually however, the dominance of the blast furnace based steel production in Western countries is corroding. The costs and environmental problems of coke production, an essential part of the blast furnace production route, is a major driver. CO₂ policies may further weaken the dominance of the blast furnace.

In order for processes to be incorporated in the analyses, sufficient data have to be available. Existing processes do not give rise to problems, but for new processes there are not always enough data. Fortunately, there are enough new processes with sufficient data to include all important types of processes. The selected processes are ready for European introduction, or are likely to be so around 2010.

The data on the separate processes allow the construction of production routes, all with a representative mix of final products for the European market. The differences between the production routes concentrate on the included iron reduction process. Named after the latter, the production routes are Blast furnace, COREX, CCF, Circofer, Circored and Midrex. For comparison there is also a scrap based route, the EAF route.

European situation
The investigation of the transition of iron and steel companies requires sufficient insight in the starting situation and recent history. Especially the developments after WWII are important. After the start of the ECSC, the European steel industry grew strongly until about 1970. This period also saw the rise of the currently dominant steel processes, the primary BOF and the scrap based EAF. Traditionally, national governments had great influence on their national steel industries, which they saw as essential for economic growth. In addition, entire regions depended on the local steel industries.

After the decline of global steel demand in the 1970s, the reorganisation of the steel industry proved a complicated process. The continuing government support of steel companies resulted in a chronic excess capacity. In the end, this support served neither the companies, nor the countries involved. Finally the governments realised that reorganisations were unavoidable. While the excess capacity has not yet entirely vanished, the 2000 steel industry is a much more liberalised sector, with room for rational decision making in the company’s interest. This is an important starting point for the included analyses.

Influence of individual factors on technology choice
Because of the different characteristics of the selected production routes, their economic performances respond differently to changes in external factors such as CO₂ taxes, electricity emission factors and the possibility for CO₂ storage. Calculations of the Net Present Value of technology shifts show that some production routes respond strongly to changes, while others prove very stable. The possibility of CO₂ storage favours CCF, in absence of CCF there is no other dominant process. If CO₂ storage is not possible, Circored thrives with higher CO₂ taxes, with lower ones, CCF is dominant again. COREX benefits from higher electricity emission factors, Circored and Circofer from lower ones.

The net costs of a shift to a new production route strongly depend on the moment of the shift. The net costs are the costs of the construction of the new processes, minus the costs
of maintaining the existing ones. The latter costs depend on when the existing equipment requires upgrading or replacement.

The SimCo model
The SimCo model, developed as part of this research, simulates the development of individual iron and steel companies for longer periods. It does so by a successive optimisation rounds of investment and production decisions for the foresight period, usually not more than ten years. Each round is two years after the preceding one. The decisions that apply to the two years in between are the starting point for the following optimisation. A multiple repetition of this procedure results in a simulation of the company’s development during a longer period. In this way, SimCo creates its own history, and incorporates path-dependency in its results. As the optimisation module in SimCo does not choose from production routes as a whole but from the separate processes instead, SimCo is capable of constructing its own production routes within the possibilities that the processes allow.

Results of company simulations
SimCo has simulated 72 scenarios in which it could choose the production processes. The varying parameters were the CO$_2$ tax, the possibility of CO$_2$ storage, and the availability of CCF. For each set of parameter values, SimCo simulated three different parallel companies, that differed in the coke oven age at the start, and the possibility to replace the coke ovens at the end of their lifetime. These parallel companies were each other’s references. In order to create additional references, there were 15 single-technology scenarios in which only one iron reduction process was available. The complexity and extent of the results impede the isolation of the influence of path-dependency. But the frequent appearance of hybrid company configurations and the variability of the transition times are striking features of the results.

Analysis of company simulations
The isolation of path-dependency from other influences requires a comparative reference based analysis. The available references are the single-technology scenarios and the parallel companies. The analyses on the influence of separate factors provide additional insight in the origins of specific results. The available references have proven to be sufficient to identify the role of path-dependency during the transition. A detailed presentation of selected scenarios supports the analysis.

Path-dependency proves to be decisive for the final company configuration in a number of locked-in situations. In other cases the influence of path-dependency is limited to a delayed completion of the transition. The influence on the economic performance is always disadvantageous, sometimes such as to endanger the company’s survival. In addition, path-dependency often causes smaller emission reductions, both in the final situation and during the transition. Path-dependency has the strongest influence when the different options are nearly equivalent. In the absence of CO$_2$ storage possibility, path-dependency often results in higher emissions. When storage is possible, its influence on the emissions is often negligible. Companies that are the fastest to proceed in the beginning of the transition, on average more often get stuck in a locked-in situation.

A striking result is the appearance of optimal hybrid configurations. These are no locked-in situations, and they perform better than the production routes they consist of.
Especially the hybrids of CCF and Circofer appear frequently when CO₂ storage is possible.

Final remarks
Path-dependency can have a great influence on the CO₂ emissions and economic performance of steel companies. In other branches of industry this may also be the case, although the effects will not always be quantifiable as in the steel industry. The main message for policy-makers is that the decisions of the individual companies do not always lead in the right direction, despite the present of policy incentives. Some cases may require the cooperation of industries and government in defining the long-term target. The government should facilitate the decisions that lead in the most direct way to the desired target. A broad inventory of the influence of path-dependency in many sectors and the identification of desirable transition results may be helpful in this case.