

## **Overview**

With its clear goals to enhance secure, and sustainable energy systems, and to combat global climate change, the European Union's 2030 Framework for climate and energy defined a three major targets, including a 40% decrease in GHG emissions compared to the 1990 levels, a minimum of 27% share of renewables in energy use, and a 30% increase in energy efficiency compared to business as usual. This strategy not only supports the transition to clean, low-carbon energy forms and technology, but also simultaneously aims to increase the energy supply security of the European Union, and encourages private investment in energy infrastructure. The European Commission estimates that the cost of meeting these long-term goals will not significantly differ from the costs that would be needed to replace older energy technologies at the end of their life-cycle.

With the aimed transition to a greener energy sector in mind, we examine the energy paths of the member states of the European Union over the period 1971-2010, with model based clustering methods. We find that most countries change their energy profiles over the examined period, and take a "path" leading towards a larger share of higher quality energy forms, and less fossil fuels in their energy mix. We also find evidence that even though income per capita in all clusters is increasing over the period, it is always the highest in low-fossil fuel or "higher energy quality" clusters. This supports the conclusion that green transitions occur as countries get richer. We do not find however evidence of similar developments in the import dependency of countries.

## **Methodology**

This paper uses a model based clustering approach to investigate energy transitions in the European Union. The underlying idea of any clustering technique is to group high-dimensional objects, which are measured along several dimensions into meaningful groups to ensure that the objects within the groups are as similar, and between the groups are as different as possible. Contrary to classical clustering algorithms, model based clustering belongs to the category of unsupervised learning algorithms, and has its foundations in probability theory.

In our approach, we model the energy transitions of the EU member states based on clusters defined by the different energy forms or dimensions in the national energy mix (including biomass, coal, oil, gas, hydro, nuclear and renewable energy forms). The final clusters correspond thus of the different energy mixes or profiles the EU member states, in the period from 1971 to 2010. While certain countries for example stay in the same cluster over the entire observation period, others move up or down between the groups, which we call their "energy path."

## **Results**

Based on these methods we found 7 distinctive clusters, which successively decrease in their fossil fuel usage, with cluster 7 having over 99% fossil fuel usage, while the best cluster showing only 52% fossil fuel share. These shares are a weighted average of the energy mixes of countries, allocated to the cluster at any point in time. We observe that decreasing fossil fuel dependency is currently only attainable with a combination of other energy forms including hydro, nuclear and renewable energy.

Very high "fossil fuel" clusters show lock-in effects, with countries never leaving, for example Cyprus or Malta, both of which cover the majority of their primary energy consumption with (imported) oil, explained by their geographic location as islands. We also find that high fossil fuel reserves like coal, are likely to cause countries to be locked in in a high "coal" consuming cluster, as indigenous resources not only tend to be cheaper but also more supply secure. Accordingly, Poland was the only EU member state, not in favor of a GHG reduction target for 2030 during a public consultation on the 2030 framework for climate and energy policies.

Nevertheless, most of the EU members show a clear path of moving towards higher quality fuel clusters, as their income increases. At the same time real income per capita is always the highest in clusters with the lowest share of fossil fuels. This supports the notion that as countries get richer, they transition towards cleaner energy forms.

## **Conclusions**

The EU's policy framework for climate and energy between 2020 and 2030 includes the specification of greenhouse gas, renewable energy and energy efficiency targets, and the reform of the emissions trading system. Further key points include ensuring competition in integrated markets, meaning the phasing out of subsidies for mature energy technologies in the given timeframe, the provision of competitive and affordable energy, and the promotion of energy supply security. The security of energy supply is of crucial importance for the EU, which imports about 53% of its total energy consumption. This figure has been continuously growing in the past years,

and is expected to increase in the future. The Commission estimates that avoided imported fuel costs due to increasing use of renewable energy amounted to at least some EUR 30 billion a year.

Our study provides a good overview of the past energy paths, the EU member states took, during past 40 years. These transitions were driven not only by economic development, and own resource availability, but also by policy and regulations. Based on this study, our further aim will be to investigate whether as a result of specific energy and environmental regulation some countries carried out the above-evidenced transitions faster, and if so, in what context will such policies be effective.