# *LOCATIONAL (IN-)EFFICIENCY OF RENEWABLE POWER GENERATION FEEDING INTO THE DISTRIBUTION GRID: A SPATIAL REGRESSION ANALYSIS*

Tim Höfer, Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, +49 241 80 49837, thoefer@eonerc.rwth-aachen.de
Reinhard Madlener, Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, +49 241 8049820, RMadlener@eonerc.rwth-aachen.de

## Overview

This paper analyzes the negative external effects caused by electricity from variable renewable energy sources (VRES) fed into the distribution grid. The resulting external costs arise from the need for feed-in management, i.e. the invervention necessary when grid operators are forced to relief grid overstress by temporary disconnecting of VRES power generation assets. During these times, the power plant operators receive remuneration for the electricity output which could have been produced if the distribution system operator (DSO) had not cut back their output. The necessity of feed-in management arises from the increased stress on the distribution grid. Whereas in the past, the distribution grid was designed to transport electricity unidirectionally from high to low voltage levels, nowadays high shares of electricity from VRES fed into the distribution grid stresses the grid in a bidirectional manner. This effect is amplified by chosing suitable locations for renewable power generation assets but ignoring the adverse impacts on the distribution grid. At times with high wind speed or high solar irradiation, the resulting feed-in of excessive amounts of electricity into the distribution grid of regions with already high installed VRES power generation capacities can lead to grid instability. In order to protect overloaded grid components, the DSO has the right to reduce the renewable power generation output in the affected areas. The resulting costs of the feed-in management for the DSO are passed on via the grid use tariffs and eventually have to be borne by the end-consumers connected to the distribution grid in question. This leads to higher grid use tariffs in regions with high amounts of renewable energies. Studies show that rural regions are more affected by feed-in management than urban areas and that the distribution grid will have to be reinforced especially in rural regions in the future (Agricola et al., 2012; Büchner et al., 2014; Ecofys and Fraunhofer IWES, 2017). This leads to the question of which spatial characteristics do have a significant impact on the occurrence of feed-in management, and how much the magnitude of these impacts vary across regions. To answer these questions, we firstly construct a unique dataset of feed-in management measures, load densities, and grid characteristics for selected DSOs in Germany, which are heavily affected by feed-in management and which feature different power supply and demand situations. The data set allows us to examine the spatial characteristics of a region in much more detail than the studies mentioned above. Secondly, we conduct a spatial regression analysis which explains the occurrence of feed-in management by taking into account the spatial differences over time within a DSO's region and reinforcements of the distribution grid.

## Methods

The spatial regression analysis of feed-in management is performed, among others, with the explanatory variables installed capacity, load density, power line length, and transformer capacity. In order to subdivide the DSO region into meaningful grid-related regions, so-called Voronoi polygons are created around the DSO substations in the high- to medium-voltage grid. The subdivision into such polygons implies that the installed generation capacity is connected to the closest substation (Egerer et al., 2014). Temporal changes within a polygon, such as grid reinforcements, increased installed capacity of renewable energies or decreasing load are tackled by incorporating data from several years. Furthermore, the data is subdivided, based on the voltage level, into three classes (high, medium, low).

## Results

Preliminary analysis shows that the type of power plant and the voltage level in which the power plant is connected, is strongly correlated with the need for feed-in management and that the level of correlation varies among DSO regions and among the predefined polygons. Furthermore, we find that the structural grid characteristics, such as power line length and transformer capacity, as well as load density, do have a statistically significant impact on the feed-in management. Finally, we find that while some polygons are heavily affected by the feed-in management, others are not affected at all.

## Conclusions

The subdivision of a DSO region into polygons around substations, combined with the spatial allocation of installed capacity, load density, power line length and transformer capacity, enables an in-depth spatial analysis of the required feed-in management. The result of the analysis is potentially useful for policy makers, DSOs, project planners and communities in meeting future challenges posed by the integration of high shares of VRES in the distribution grid. Policy makers could use the results to enhance the current tender model for photovoltaic systems and wind turbines by incorporating the condition of the distribution grid, in order to internalize external costs caused by feed-in management. Project planners and communities required to minimize the external costs of VRES power generation units will then have to take the magnitude of stress on the distribution grid of a DSO subregion explicitly into account by choosing the most suitable areas for the location of renewable energy power plants. DSOs, irrespective of whether they already experienced feed-in management or not, can use the results to locate areas where they have to strengthen the capacity of the distribution grid in the future in order to avoid (or at least mitigate) feed-in management.

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