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Spatio-Temporal Mapping of the Diffusion of Residential Solar Photovoltaic Technology in Luxembourg (2017-2023)

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Abstract:

Residential Solar Photovoltaic (RSPV) systems represent a viable and bottom up mechanism for advancing partial energy autonomy and enhancing national energy resilience. Through observation or government statistics it can be acknowledged that we have witnessed an increase in their implementation in the last 10 years driven by advances in the technology and early adopters with eco-centric viewpoints embracing these new decentralised forms of energy production. In Luxembourg (and across Europe) we have observed a rapid increase in RSPV implementations occurring over the last 3 years. This has been driven by the need for price stability and affordability as well as very favourable subsidies. Nonetheless, a myriad of barriers hinder progress, spanning from overarching national policies and inadequate incentives that favour the most affluent in society to individual preferences and attitudes based on worldviews or confidence in understanding the technology. Literature suggests that the visibility of RSPV installations can both impede and facilitate diffusion, influenced by societal dynamics and differences.

Luxembourg currently lags behind its neighbouring countries in renewable energy adoption, with only 6.85% of its energy sourced from domestic renewable sources. Among these, solar energy technology contributes a mere 1.75% (Ritchie et al., 2022). Previous research indicates that a scant 4.1% of residential properties in Luxembourg have embraced solar photovoltaic technology (Skinner and Jones, 2024). In the absence of an openly available dataset that documents PV implementations we set out to develop a solar implementation cadastre for Luxembourg over the time period of 6 years (2017-2023). This time period allows for a general pattern to emerge whilst also allowing for comparisons between the pre- and present energy crisis. We achieve this by undertaking a spatio-temporal analysis of Luxembourg to model the pattern of RSPV technology adoption. The results of a LISA analysis permit us to examine areas with higher solar PV uptake and assess whether this adoption pattern emanates outward from prominent installations, referred to as flagship properties. By investigating the potential for a localised "multiplier effect", the study seeks to shed light on whether prominent installations and world events act as catalysts for wider adoption, thereby accelerating the transition towards renewable energy.

We use deep learning methods applied to publicly available orthoimagery from https://data.public.lu/fr/ to identify residential solar roof top solar PV installations. A CNN (Convolutional Neural Network) is a deep learning model commonly used for image recognition and classification tasks, where it learns hierarchical patterns by convolving filters over input images to extract features and then passes them through fully connected layers for classification. Utilising region-based CNN models, solar PV detection is conducted on a series of orthoimagery spanning from 2017 to 2022. We train the machine retrospectively. First starting with the highest resolution imagery from 2022 and creating our training dataset and then for previous years (2023 data is not yet available). By analysing spatial patterns of solar PV distribution over time, particularly in areas known to have flagship properties in 2017, the study aims to discern if there are observable trends indicative of diffusion emanating from these locations. A CNN model with 87% accuracy has been developed for later orthophotography (2019-2023) at a 10cm resolution. Additionally, another model for detecting solar PV on 20cm resolution imagery is currently in development, expected to achieve similar accuracy.

The model creation process involved utilising ArcGIS's image classification and deep learning tools. A meticulous examination of seven contrasting communes was conducted to obtain labelled polygons containing imagery of solar PV for both training and testing purposes. Subsequently, these labelled datasets were utilised to train the model to detect solar PV across the entirety of Luxembourg. To assess the effectiveness and accuracy of the trained model, a separate evaluation was conducted using an additional set of seven contrasting communes. Employing a random sampling technique, the evaluation process involved selecting random samples from the communes using a random number

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generator in conjunction with the building's polygon identity number. This rigorous approach ensured unbiased ground truthing, providing reference data for comparison against the model's predictions.

The quantitative analysis will also involve GWR modelling to examine the spatially varying relationship between visibility, as indicated by solar PV presence, and the rate of RSPV adoption across different geographic regions. By allowing regression coefficients to vary spatially, GWR can provide insights into how the impact of visibility varies geographically, accounting for local contextual factors such as socioeconomic and demographic characteristics, and the policy environment with a particular focus on subsidy levels.

We do observe spatial-temporal clusters in the east of the country which is characterised by rural towns with building consisting of large footprints. Towns and cities of the south remain *Residential PV deserts* due to the more industrial landscape, smaller building footprints, compact urban form and less affluent neighbourhoods (Skinner and Jones, 2024). Moreover, the spatial-temporal clusters do follow trends whereby there are patterns of emanation, or elongation of RSPV clusters along road networks.

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References

Orthophoto officielle du Grand-Duché de Luxembourg, édition 2022 (ortho_2022) - Portail Open Data (no date). Available at: **https://data.public.lu/fr/datasets/orthophoto-officielle-du-grand-duche-de-luxembourg-edition-2022/**

Ritchie, H., Roser, M. and Rosado, P. (2022) ‘Energy’, Our World in Data [Preprint]. Available at: https://ourworldindata.org/energy (Accessed: 12 June 2023).

Skinner, A., & Jones, C. (2024, April 10). Exploring the Spatial and Built Environmental Characteristics of Residential Solar Photovoltaic Implementations in Luxembourg. 32nd Annual GIS Research UK Conference (GISRUK), University of Leeds, Leeds, UK. https://doi.org/10.5281/zenodo.10926740

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