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Assessment of policy based residential solar PV potential using GIS-based multicriteria decision analysis: A case study of Apeldoorn, The Netherlands.

B.B.Kausika*, O.Dolla, W.G.J.H.M.van Sark

Copernicus Institute of Sustainable Developemt, Utrecht University, Heidelberglaan 2, 3584CS, Utrecht, The Netherlands

Abstract

The Postal Code Rose policy is part of the 2013 Dutch Energy Agreement of the Social and Economic Council of the Netherlands, introduced to support sustainable energy growth. This paper presents a case of the Dutch Postal code Rose policy by developing a method combining geographical information systems (GIS) and multicriteria decision analysis (MCDA), which allows determining the solar photovoltaic potential when fully applying this policy. As case study, the city of Apeldoorn in the Gelderland province of the Netherlands was selected. The research evaluates the technical potential of the city and then applies it to the Postal code Rose framework by using social criteria. The social criteria comprise of the most important factors that play a role in the adoption of solar PV. The results showed that by fully applying the Post Code Rose policy ~77% of the total electricity demand of Apeldoorn could be covered by solar PV.

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Keywords: Solar; PV potential; policy analysis; geographic information system; multicriteria decision analysis.

* Corresponding author. Tel.: +31 30 253 4291.
E-mail address: b.b.kausika@uu.nl

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1. Introduction

In recent years, the rapid depletion of fossil fuels and its association with climate change pushed the renewable energy technologies to the forefront. Diffusion of renewable technologies is of interest to policy makers and national agencies who wish to tackle global climate change. For example, the EU has defined its 20-20-20 goal: 20% reduction of greenhouse gas (GHG) emissions, 20% renewable energy and 20% reduction in energy use by 2020 [1]. In the Netherlands, a policy program called “Clean and Economical” (in Dutch: “Schoon en Zuinig”) from the Ministry of Housing, Spatial Planning and the Environment [2] has been introduced. This policy originally set a target of a 30% GHG emission reduction in 2020 compared to the levels of 1990 and 20% of the total energy demand covered by renewable energy sources. After a few years, these targets were reset to 20% reduction of the GHG emissions and 14% renewable energy production by 2020 [2].

Policies indirectly affect the reduction of GHG’s, by aiding the decision of adoption of renewable energy technologies. Policies can also induce change at the smallest scale: at household or an individual level. An example is the postal code rose (PCR) policy: a sustainable energy initiative, introduced by the Dutch government. It targets to increase energy generation using solar panels by local cooperatives. Investment in solar panels becomes attractive under such policies. In addition, the driving factors of solar photovoltaic (PV) adoption vary from financial, information regarding the technology and social learning. It is advantageous to look at the policy implications from a spatial perspective as it could provide insight as to which places have a high potential for the policy to succeed. This also provides information on the spatial patterns of PV diffusion which is of interest not only from a scholarly perspective, but also from a policy and marketing perspective [3].

As an attempt to quantify the potential for PV systems, that would be possible as part of the PCR policy, this paper presents a method to estimate the PCR potential for a city (Apeldoorn) in the Netherlands. The method uses a combination of multi-criteria decision analysis (MCDA) and geographical information system (GIS) modelling. The MCDA method is suitable for comparing different factors that play an important role in the adoption process of solar PV, and GIS helps with the spatial analysis of the criteria.

1.1. Postal Code Rose Policy

In 2008, the Dutch Ministry of Economic Affairs introduced a subsidy for power generation from solar panels, as part of the subsidy scheme renewable energy (SDE, “Stimulering Duurzame Energieproductie”). The subsidy was at € 0.33 /kWh with a payback period of 15 years (Renewable World Energy Press, 2008). After this, the development of solar energy was so fast that in 2012 the installed capacity from 146 MW rose to 371 MW. After the second half of 2012, PV became more attractive under the national investment subsidy of “energy and innovation” which provided a grant up to 15% of the investment cost for each system above 0.6 kWp and a maximum of € 650 per system. The budget was up to € 22 million and in 2013 it increased to an amount of 30 million. In terms of statistics, in February 2013 there were 52,221 solar system owners and in September 2013 this number increased to 106,998 and 665.47 MW of solar PV capacity installed [4,5]. By the end of 2015, about 400,000 system owners together have 1.5 GWp installed [6], see Figure 1.

Recently, the Social and Economic Council of the Netherlands introduced the Energy Agreement in order to accelerate the pace of renewable energy technologies deployment mainly focusing on off-shore wind. This agreement includes ten components that are linked to renewable energy, innovation and export, transmission network etc.

Without detailing the others, the third component of the Energy Agreement states that the main target is to decentralize the generation of renewable sources by people themselves and by cooperative initiatives [7]. Apart from the tax relief of € 0.075 per kWh (in 2013, changed to € 0.09 per kWh in January 2016), the policy focuses on the electricity generation by a cooperative or by an association of owners. This energy should be utilized by small-scale consumers and members that should be located within the postal code area surrounding the postal code in which an investor is registered [7]; this was termed as postal code rose (in Dutch “postcoderoos”), mimicking the rose flower with a central core and surrounding petals. To understand PCR (Figure 1(b)), suppose there is a sustainable energy initiative in the post code 7331, each participant in the zip codes 7333, 7334, 7335, 7311, 7321, 7328, 7332 and also 7331 itself can avail the so-called energy tax reduction on every kWh generated which is in proportion to the total yield of the overall project. The idea is that participation in the joint project will mean 50% return on the energy, along with returns from the project.

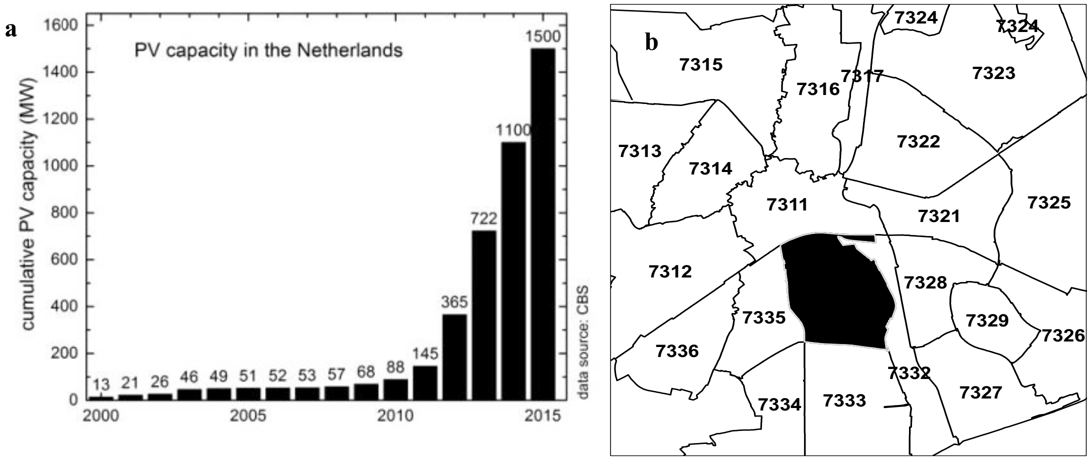

Figure 1:(a) Development of cumulative installed PV capacity in the Netherlands (data from CBS (2016)). (b) Postal Code Rose around a central postal code.

1.2 Factors Affecting Policy Diffusion

Studies have been performed in order to explore the characteristics of technology diffusion, such as the role of policies [8,9], and the social interactions towards a new product and economic factors [10,11]. When it comes to factors influencing the adoption of solar PV, there is little said and not all the factors have been addressed together. Studies show how consumer behaviour changes if a neighbour has PV or how income and knowledge affect financial incentives [3, 12–20]. This paper addresses socio-economic factors mainly due to data constraints. Since, the focus is on policy at household level, we considered the following factors which were identified as quantifiable and relevant to the PCR policy.

- Economic factors like house value and average income
- Social factors/ peer effects
- Technical/knowledge factors

2. Data and Method

Data relating to socio-economic factors like household value, average income and electricity consumption were available at neighbourhood level. Since the PCR policy works at 4-digit postal code (PC4) level, all the data was aggregated to PC4 level. The procedure of building the database in GIS was made by ArcGIS 10.2. In order to implement the MCDA, the criteria that will be used for the evaluation must be expressed in quantitative values. Multicriteria evaluation of a problem is not easy, either economically or mathematically. Usually there is no optimal solution and hence the influence and the weighting of criteria should be adapted according to the problem. The methodology shown in Figure 2 consists of the following steps:

- Development of a digital GIS database that includes all spatial information.
- Determination of the evaluation criteria/sub criteria for the multiple criteria analysis.

- Implementation of the analytic hierarchy process method to calculate the criteria/sub criteria relative importance weights.
- Implementation of a MCDA to reveal the potential of PV capacity of the PCR policy.

When it comes to site selection problems or suitability models, the spatial MCDA (Weighted Overlay) is the most commonly used method [21]. Assigning weights to each criterion in a scientific way is necessary to ensure replicability and robustness of the model. Therefore, the Analytical Hierarchy Process (AHP) [22–24] was used to pairwise compare the criteria instead of assigning weights to each criterion directly. The steps of AHP which were implemented are as follows:

- Determine significant criteria.
- Set up criteria comparison matrix and grading.
- Normalize the comparison matrix.
- Check for consistency

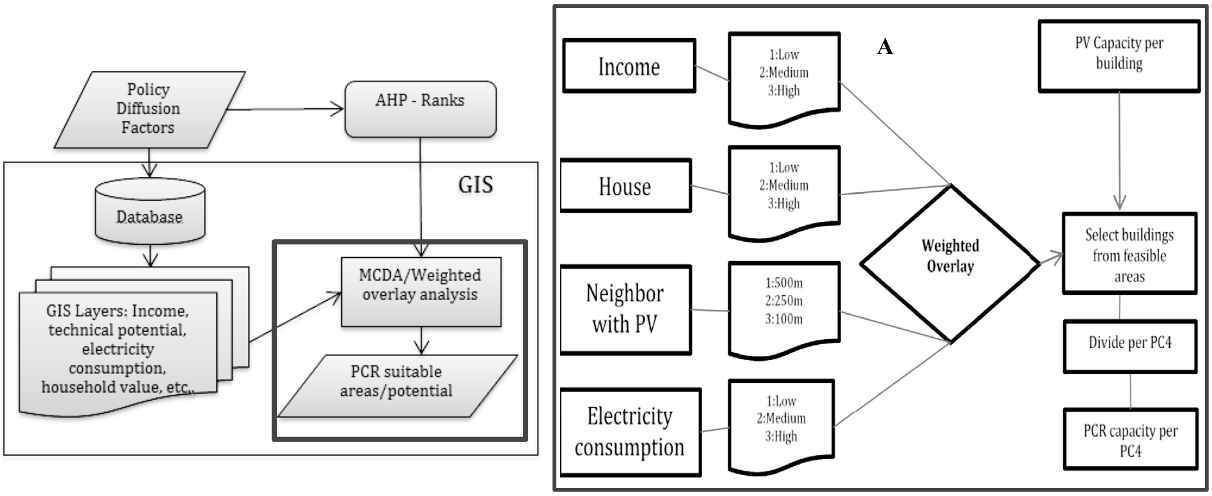

Figure 2: Methodology flowchart. (A) shows in detail the weighted analysis highlighted in the left image.

After the grading, the influence or weights of each criterion is known. The influence is then used in the weighted overlay analysis in GIS. The flow diagram of the weighted analysis and the final determination of PCR potential per PC4 are shown in Figure 2 (A). All the criteria layers were divided into 3 sub categories and graded accordingly (1-3 in this case). For example, the income factor is divided into 3 sub categories: high, medium and low and has been graded as 3, 2, and 1, respectively. The grades depict the importance or the weight of each sub criteria. This means that if the income is high then the chance of PV adoption is higher, therefore, it is graded at 3. Similarly, for peer effects, the closer the neighbour with PV the greater the influence. In this case, buildings with existing PV panels have been mapped. For these buildings, a buffer up to 500 meters was calculated in 3 steps in order to see which buildings could be affected from the peer effect that increases the probability of solar PV adoption.

The technical PV potential for the residential sector of the whole city was calculated using high resolution Lidar data. The PV capacity estimated per building was analysed by determining the rooftop suitability for PV siting and applicable calculations to estimate the capacity that can be installed [25]. This information was used after the weighted overlay, as a mask to single out buildings or suitable adopters.

3. Results

According to the data provided by the municipality of Apeldoorn, the income, house value and electricity consumption available at neighborhood level was aggregated to post code level and mapped, see Figure 3. For neighborhoods that have no data, average values were used, so that it would result in a better estimation. The low-income category is neighborhoods with income up to € 30,000. The second category is between € 30,000 and € 40,000 in which most of the neighborhoods are included. The last category is the optimal category for investing in Solar PV with more than € 40,000, as a significant amount of capital investment is needed. Similarly, house value and electricity consumption were divided in 3 categories as shown in Figure 3. It is evident from Figure 3 that the socio-economic demographics vary spatially. Low income groups are concentrated around the city centre, with low house values and high electricity consumption. As we move from the centre to the sub-urban parts of the city, the income is higher and the house value also increases.

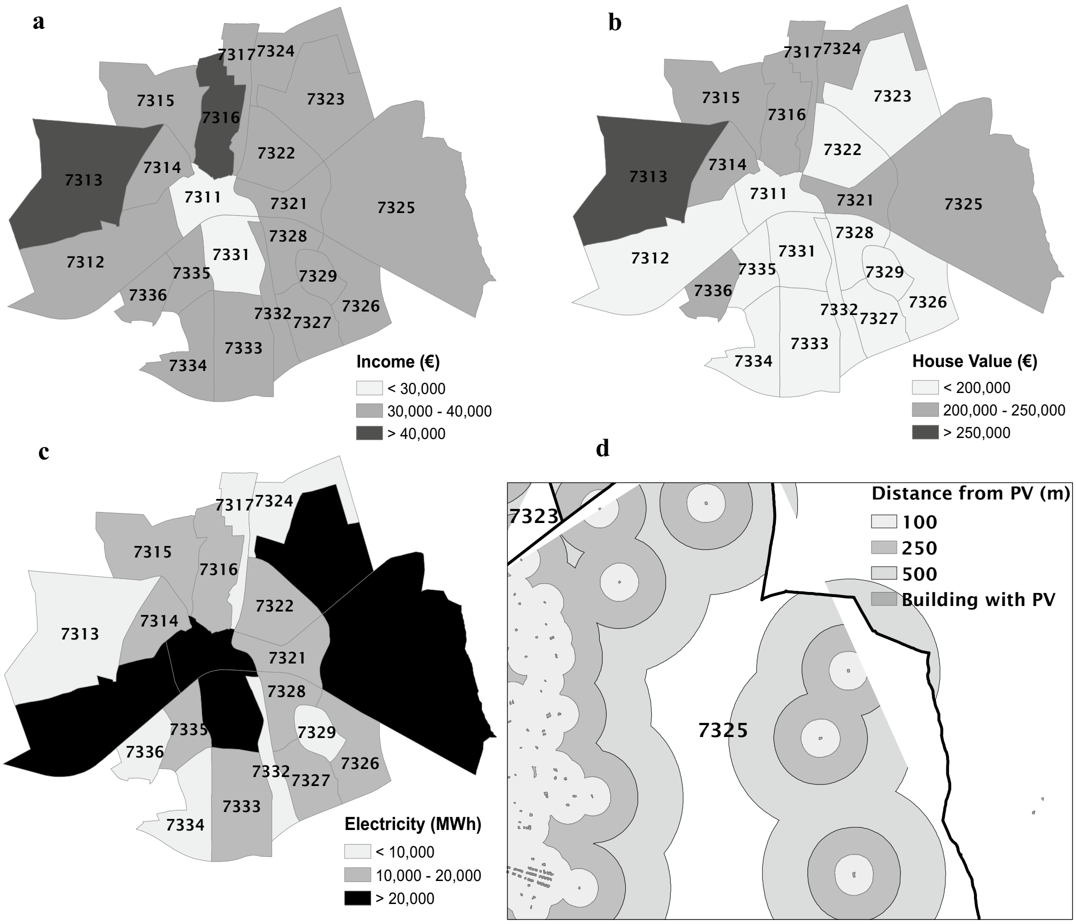

Figure 3: Map Layers after the categorization of criteria. (a) Income; (b) House Value; (c) Electricity consumption (d) Neighbor with PV within 500 m.

Table 1: (A) Pairwise comparison matrix for selected criteria. (B) Grading of criteria based on relative comparison [23].

A	B

Criteria	Income	House value	Electricity consumption	Neighbor with PV
Income	1.0	3.0	4.0	3.0
House Value	0.33	1.0	3.0	1.0
Electricity consumption	0.25	0.33	1.0	0.33
Neighbor with PV	0.33	1.0	3.0	1.0
Total	1.91	5.33	11.0	5.33

Scale	Degree of preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance

The technical PV potential was estimated at 275 MWp for the residential sector of Apeldoorn. According to the registry about 2,279 panels with a capacity of 5.8 MWp have already been installed in Apeldoorn by 2015.

In Table 1(A), the pairwise comparison of the four criteria is shown. AHP, i.e. the final grading after the normalisation of the pairwise comparison matrix and the ranking of the criteria (Table 2), was performed on data from Table 1. For example, the income of a household is considered more important than the house value (to be able to adopt PV), then a value 3 is given which means that the income factor is moderately more important than the house value factor, see Table 1(B). Regarding the values that are less than 1, it means that the second factor compared is more important e.g. House value/Income =1/3 = 0.33.

The result of the combination of the four adoption criteria is the suitable areas that have higher probability of adoption. A weighted overlay analysis of all ranked criteria (based on Table 2) performed in GIS shows the most feasible adopters of solar PV. Furthermore, combining the suitable buildings with the suitable adopters with design of PCR policy gives the PV potential of PCR policy per postal code. Figure 4(a) shows the favorable regions of for PV adoption. The green color shows the suitable areas and the red color the ones that are not likely to invest in solar PV.

Table 2: Final ranking of criteria and scoring

Criteria	Influence	Rank
Income	50.7%	1
House Value	20.4%	2
Electricity consumption	20.4%	2
Neighbor with PV	8%	4

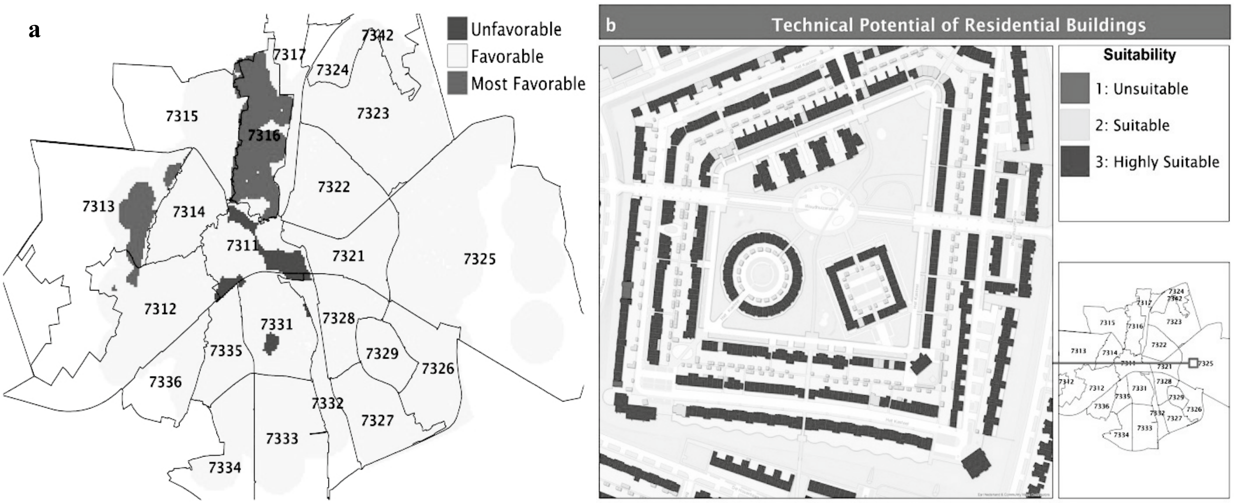

Figure 4: (a) PCR areas showing probability of solar PV adoption. Areas in green are likely to have the highest number of adopters, areas in red are least likely and areas in yellow could go either way. (b) Technical Potential map showing suitable and unsuitable rooftops (detail of postal code 7325).

Combining the PCR areas with the buildings suitable for PV siting (Figure 4(b)) from the current status scenario, shows buildings that have a higher probability to adopt solar PV based on PCR policy. This final result is shown in Figure 5. Buildings that are within unfavorable areas (denoted in red) are excluded. Postal code 7316 and parts of 7313 were found to be the most suitable to adopt solar PV. Postal code 7311 has neighborhoods where solar PV adoption is not favored due to low income and low house values even though it is characterized by high electricity consumption. The peripheral postal codes, i.e., 7315, 7316, 7317 etc., would have influences from adjacent postal codes which are not considered in this case. This means that the PCR capacity from these postal codes could be underestimated or over estimated. For the central postal codes, i.e., 7311, 7314, 7321, 7322, 7328, 7329 and 7331, the PCR capacity can be estimated applying the full potential of the policy. They are perfect examples of the potential effect of PCR policy. These postal codes are also the ones with the highest potential as can be seen from Figure 6. The PV potential after applying the policy was found to be 260 MWp. The difference between the full technical potential and the potential after policy implementation is very little (3.5%).

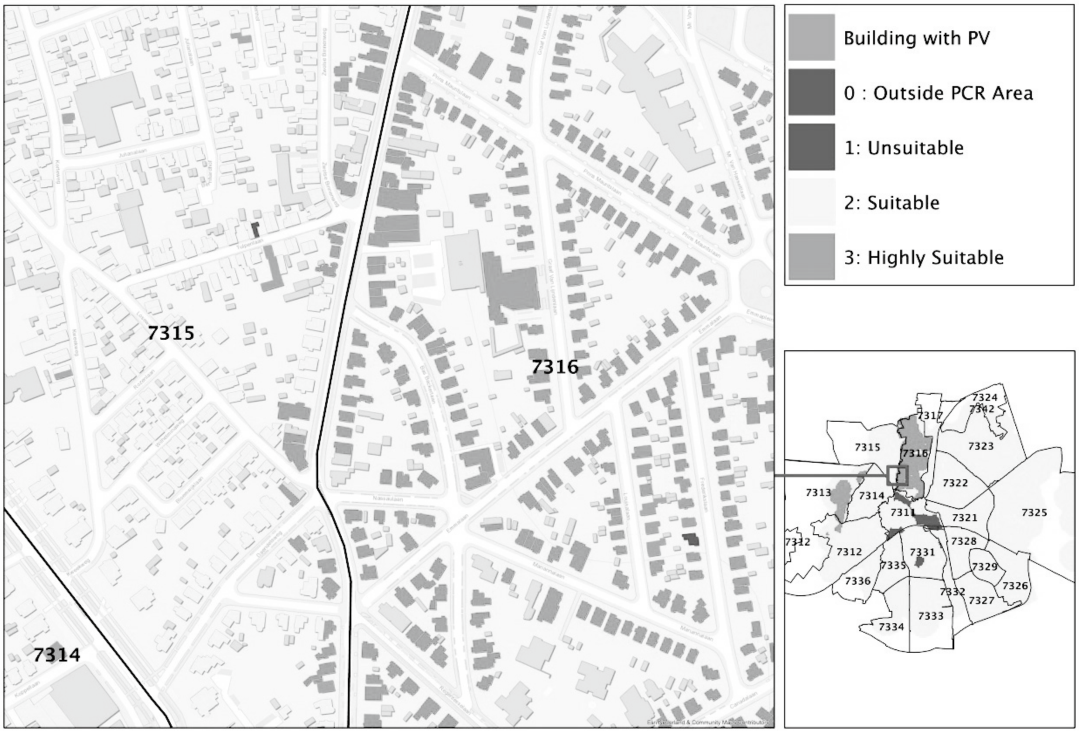

Figure 5: Residential buildings that could adopt solar PV due to PCR policy.

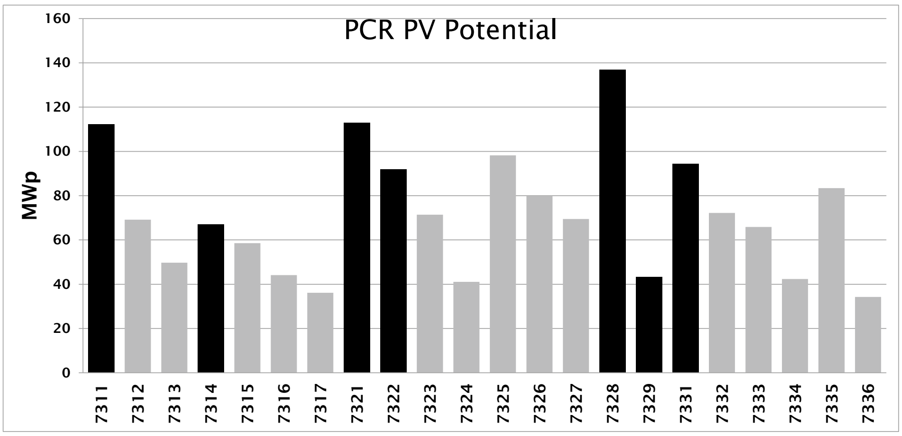

Figure 6: PCR capacity per postal code in MWp with the central postal codes in black.

4. Discussions

This paper has shown that the combination of a multi-criteria analysis and GIS can make it easier to understand and analyse policy incentives for decision makers that target local PV adoption. By using illustrative maps, decision makers can solve accurately a lot of problems. This study has shown how a complex policy can be further decomposed to simple parts that can be communicated to and by anyone.

By applying certain necessity and sensitivity tests and analyses, policy makers can be aware of the factors that play a significant role in the decision-making problem. This will provide them with the knowledge of which factor they should be more aware of and which factors need to be improved in quantitative terms. Hence, it can improve and optimize the criteria combination, change the analytical structure and reduce the sensitivity in criteria grading and make results qualitatively better, stronger and more convincing.

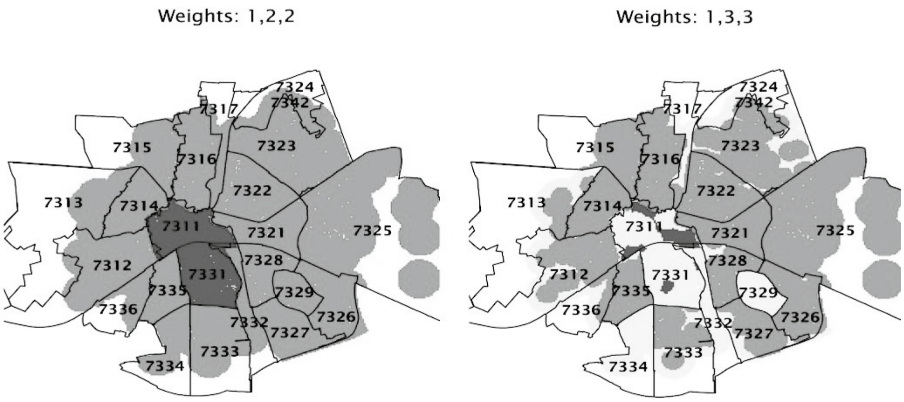

Figure 7: Sensitivity due to change in weighting.

Regarding the limitations of the research the main issues come from the fact that social criteria were used in the research. This means that usually high uncertainties express this kind of data and grading of the criteria is highly dependent on the geographic conditions. In addition, the weighting analysis requires the grading/scaling of sub criteria. This means the weights should be assigned to the sub criteria as well and this has an impact on the final results. For example, in the analysis since all the factors were graded on a scale of 1-3 they have been weighed accordingly. If these weights were changed, for example all the factors (sub criteria) are now graded as 1, 2 and 2 i.e. the medium and high groups are given equal weights, the final result shows sharper boundaries as shown in Figure 7. Varying the weights of the sub criteria gives different outputs.

Data availability was one of the main limitations of this research, which was due to the fact of privacy restrictions regarding the residential sector. The methodology that was implemented might underestimate the PV potential and therefore the final probability of adoption, as the criteria for PV potential analysis were conservative, i.e., the area should receive more than 50% of the average irradiation of the area and rooftop availability for PV siting was set at 40%.

In future research, the inclusion of more necessity and sensitivity tests are expected to overcome the shortcomings of this research and many repeated operations of the MCDA and GIS models that were used for this research. More criteria are expected to be used that could better and more accurately forecast the adoption of solar PV systems such as environmental awareness of the adopter, and NIMBY effect etc. In addition, the inclusion of factors like age and knowledge could provide valuable insights. Furthermore, more detailed and better quality data for the selected criteria could be used that would give more accurate results and finally a wider potential analysis that would not only be used for a specific area or city but for the whole country of the Netherlands could be developed.

5. Conclusion and policy implications

This paper discussed the main drivers that could play an important role in the decision-making process of the residents regarding solar PV. GIS is very useful in exploring spatial relationships of complex problems like policy effects as shown and using these tools helped in the estimation of the maximum solar PV potential by applying four technical criteria: solar radiation, slope, elevation and orientation.

In order to apply the PCR policy to the maximum solar capacity four social criteria were applied which according to literature were the most important ones for the adoption of solar PV: income, house value, neighbors with PV and electricity consumption. The analysis of the policy was made on 4-digit postal code level that revealed that the potential after the application of the policy is 266 MWp for the case of Apeldoorn.

Using the established annual yield number that is used by the Dutch Statistics Bureau (CBS) of 875kWh/kWp [26], the amount of annual PV energy that could be generated is 222.75 GWh, which is ~77% of the average electricity demand of the city of Apeldoorn.

This methodology can be applied for any city or neighborhood that wants to apply the PCR policy. It showed that apart from the fact that there is a significant solar PV potential there are also factors that influence the solar PV diffusion such as social factors and are catalytic for the adoption of this technology. Furthermore, local and national authorities should take into account this kind of factors so that policies could capture the social effect of the adopters. If changes will be realized from the core level which is a small community this would facilitate the road to reach the ambitious national goals.

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