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PV on noise barriers

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Abstract

PV on sound barriers has been around for 14 years during this time considerable progress has been achieved not only on the PV module technology but also in the construction of photovoltaic noise barriers (PVNB). The first plant was built in Switzerland in 1989; at the present there are numerous plants with a total documented power of about 850 kWp in operation in Europe. This paper gives a short overview on the progress and state of the art of PVNB in Europe.

Why PV on sound barriers?

In some European countries noise protection measures along motorway and railway systems in built up areas is now required by legislation. In these countries the requirements have now been identified and the noise protection structures are planed or already under construction. Using these noise barriers as substructures for PV modules or to integrate the PV modules into the sound barrier system has many advantages.

Double use of land resources:
The strip of land along a rail or road infrastructure in a built up area, can be utilised for noise protection and also for the placement of PV modules to produce electric energy.

High potential:
There is a high potential for photovoltaic noise barriers (PVNB) especially in highly populated and industrialised areas, which also have a high usage of electric energy. In recent studies the potential to produce electric energy along motorways and railways in Europe was quantified.

Bulk prefabrication:
Mechanical and electrical prefabrication of photovoltaic or complete photovoltaic noise barriers (PVNB) subsystem was exercised in most of the grid connected PV plants built along transport infrastructure in the past 14 years.

Public ownership:
A highway project, including noise protection, is usually a public project and the additional PV plant can be included in the finance plan, the planning and building process as a whole.

Easy access
The transport-ways can be used for the construction and maintenance of the PVNB systems. Appropriate transport vehicles are already available for general road or rail maintenance.

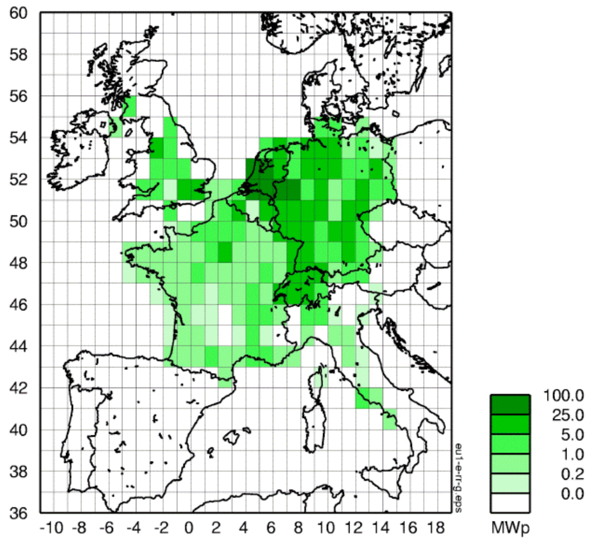
Potential

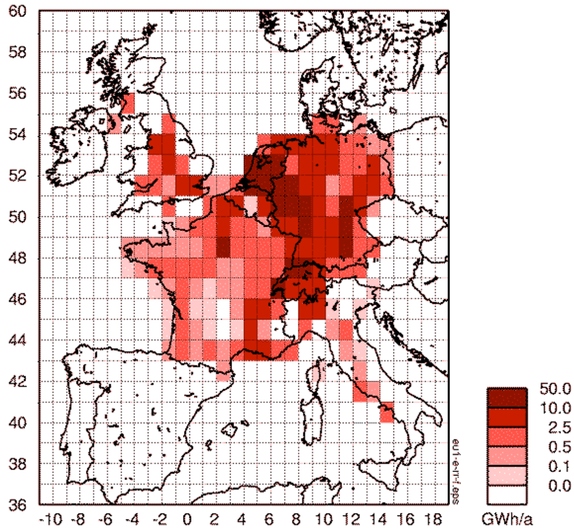
In a European study carried out by 7 partners of 6 countries the energy potential of PVNB was quantified [3, 6, 7]. Existing as well as planed road and rail systems were considered. The theoretical potential, technical potential and short-term potential were calculated for the participating countries. The technical potential represents the existing and the planed road and rail sound barriers within the next five years. The generating capacity was calculated considering the topology of the transport system as well as the meteorological data for the relevant region.

Technical Potential		CHE	DEU	NLD	GBR	ITA	FRA	Total
Noise Barriers								
Along Motorways	[km]	303.8	1,525.0	475.9	204.0	50.7	352.2	2,911.7
Along Railroads	[km]	94.7	600.0	444.6	16.5	7.0	139.0	1,302.1
Generating capacity								
Along motorways	[MW_p]	58.5	293.8	114.6	39.3	9.8	67.9	583.9
Along railroads	[MW_p]	14.9	94.5	82.4	2.6	1.1	21.9	217.4
Total	**[MW_p]**	**73.4**	**388.3**	**197.0**	**41.9**	**10.9**	**89.7**	**801.3**
Electrical energy generated								
Along Motorways	[GWh/a]	53.4	247.5	91.8	29.9	10.3	63.7	496.6
Along Railroads	[GWh/a]	13.6	82.4	65.6	2.0	1.2	21.4	186.1
Total Energy yield	**[GWh/a]**	**67.0**	**329.9**	**157.3**	**32.0**	**11.5**	**85.1**	**682.8**

Table 1: Technical potential of the generating capacity and the electrical energy generated along the road and rail systems of the six countries investigated.

The technical potential for the six countries is a generating capacity of 800 MWp generating 680 GWh of electrical energy per annum (Table 1). Because of the different stage in the planning and realisation of noise protection measures in Great Britain, Italy and France, only existing noise barriers were considered, a realistic potential for these countries would be considerably higher.





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Figures 1 + 2: Geographic distribution of the generating capacity and the electrical energy generated.

Examples

The first PV plant on sound barrier was built in Switzerland in 1989 [4]. Others followed in Austria, Germany and the Netherlands.

Country	Plant	Installed	Costs	P_0	max. Yield	Year	Irradiation	
			[EUR / Wp]	[kWp]	[kWh / kWp]		[kWh / m^2]	
CHE	Domat/Ems A13	1989	16.27	103	1,211	1997	1,522	[9]
CHE	Magadino SBB	1992	13.50	103	935	1999	1,473	[9]
AUS	Seewalchen A1	1992	13.50	40				
DEU	Rellingen A23	1992		30				
CHE	Giebenach A2	1995	12.08	104	969	1997	1,152	[9]
DEU	Saarbrücken A6	1995	8.00 (9.40)	60				

NLD	Utrecht A27	1995	10.50	55				
DEU	Ammersse A96	1997		28				[8]
CHE	Zurich	1998		26				[8]
NLD	PVNB 220 A9	1998	10.61	220	795	1999	1,047	[2]
CHE	Alpha A1	2000	7.0 +	75	805	2001	1,176	[9]

Table 2: Overview of some large documented PVNB plants in Europe. The column (max. Yield) shows the maximum annual yield achieved by the plant over the period monitored. The next two columns show the year and the corresponding irradiation in the array plane. For the projects Ammersee and Zurich detailed information is given in the Tables 3 and 4.

The average size of these examples is 77 kWp. The largest plant is the PVNB plant in the Netherlands (220kWp) built in 1998. Over the years there was a significant reduction in the overall costs this type of plant from 16 to 7 EUR / Wp. This mainly due to the fall in the price of the PV modules but also because of the experience gained from previous projects in terms of planning and construction and a higher level of integration. The energy produced by a PV plant along a motorway depends, as it does with all PV applications, mainly on the efficiency of the PV module, the geographical location of the plant and the orientation of the PV array.

100kWp Domat/Ems A13, CHE

Built in 1989 this 100 kWp plant still delivers 1,000 kWh / kWp per annum to the local grid [4]. The glass surface of the modules was never cleaned and significant degradation of the array efficiency has been observed. The plant operated without any major interruptions for 10 years. During the 11th and 12th year there were a series of major interruptions and some minor but important components of the inverter unit had to be replaced. The reaction time between interventions was quite high. Since May 2002 the plant is back in full operation.

Figure 3: PV Plant Domat/Ems A13 in Switzerland.

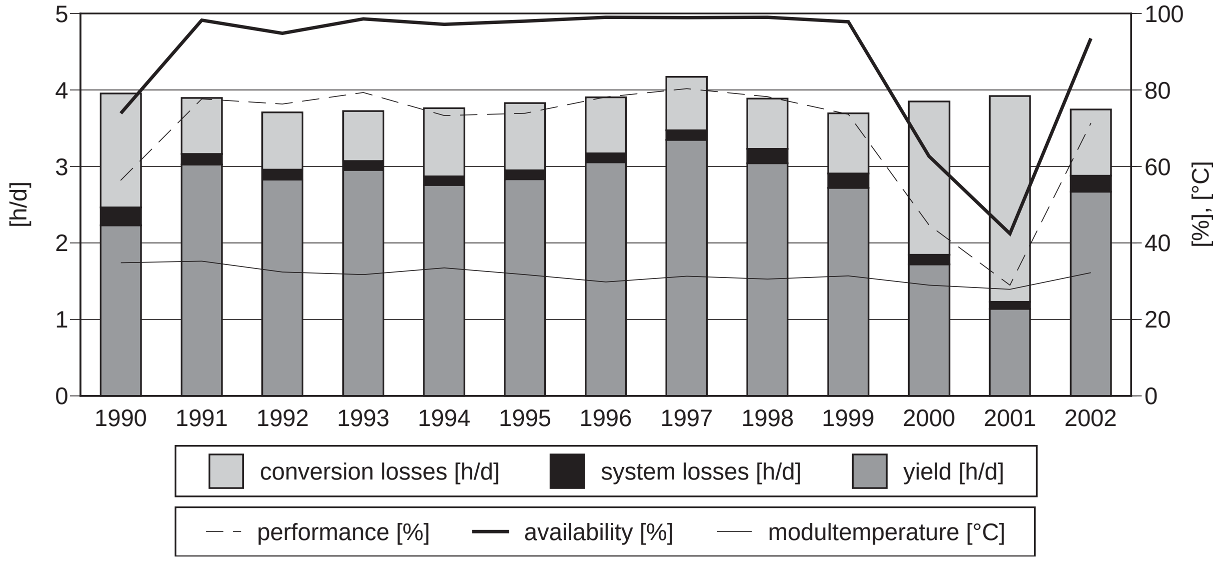

Figure 4: Monitored data over 13 years of operation, PV plant Domat/Ems.

This is first plant built of its type and for the first ten years has shown to be very reliable in its operation. It is also highly visible and has quite an educational effect. As it is a retrofit installation some additional construction measures to the existing sound barrier were necessary. It was demonstrated that for this type of layout there was no significant reduction of the energy produced due to the deposit of dirt from the motorway.

100kWp Giebenach A2, CHE

This 100 kWp plant was built in 1995 and on average produces 850 kWh / kWp. The modules face away from the motorway, it was therefore possible to have a wider and therefore shorter area for the PV array.

Figure 5: PV Plant Giebenach A2 in Switzerland.

This plant has demonstrated that the PV array can also be placed facing away from the motorway. This means in a situation with sound barriers on both sides of the motorway, it would be possible to have a PV array on either side, one facing the motorway and the other on the opposite wall facing the outside.

220kW PVNB 220 A9, NLD

This large 220 kWp plant near Ammersfort along the A9 comprises 2160 100 W modules each with a 100 W micro inverter [2]. Initially intensive testing of the 2160 micro inverters was necessary and due to malfunctioning some units had to be replaced. Now the plant performs as expected.

Figure 6: PV Plant PVNB 220 A9 in the Netherlands.

This plant demonstrates the possibility of a large application with a large number of module-integrated inverters. At a time of construction the technology was relatively new and after the initial interventions the micro inverters were found to be reliable with no electrical interference between the units.

75kW Alpha A1, CHE

This 75 kWp plant has 24 mini inverters. Unfortunately there is some shading of the lower row of modules during the summer months.

Figure 7: PV Plant Alpha A1 in Switzerland.

Design competition

In 1996 a design competition for noise barrier designers, PV-suppliers and PV-installers was launched Germany and Switzerland, resulting in the construction of three 10kWp PVNB plants in Germany and three 10kWp PVNB plants in Switzerland [1,8]. All the plants are a unique combination of noise protection and PV-technology. The six innovative prototypes are showpieces and living examples of PVNB along road and rail. All the plants were initially monitored for two years. Table 3 and table 4 show annual yield, irradiation and the mean module temperature for each plant during the monitoring period. The variation in the module temperature is due to the different construction of PVNB array.

Germany

Plant	Installed	Type	P_0 [kWp]	Yield [kWh / kWp]	Year	Irradiation [kWh / m^2]	T Module [°C]
Fabrisolar	1998	Cassettes	8.77	751	97/98	1,162	40.9
Zueblin	1998	Shingles	9.13	814	97/98	1,219	43.9
DLW Metecno	1998	Zig - Zag	10.08	794	97/98	1,032	27.0

Table 3: Three 10 kWp pilot plants in Germany.

The three Ammersee plants are along the A96 motorway near Munich and are easy accessible from the lay-by.

9kWp Fabrisolar, DEU

The Ammersee Fabrisolar plant is with cassette technology and one single inverter. This PVNB is a combination of sound reflection and sound absorption.

Figure 8: Ammersee Fabrisolar, cassette technology.

9kWp Zueblin, DEU

The Ammersee Zueblin plant has shingle technology and multiple micro inverters. This PVNB is a combination of sound reflection and sound absorption.

Figure 9: Ammersee Zueblin, on the left, with shingle technology.

10kW DLW Metecno, DEU

The Ammersee DLW Metecno plant applies zig – zag technology and one single inverter. This is a sound reflective PVNB plant.

Figure 10: Ammersee DLW Metecno with zig – zag technology.

This R&D project in Germany was carried out by TNC as part of the international design competition. As all the plants are located in the same parking- and rest area along a motorway near Munich it allows for a side-by-side comparison of the designs. The Fabrisolar design in figure 8 utilises a new type of layout with a relatively compact design. The Zueblin design in figure 9 could also to be used in a retrofit situation. The DLW Metecno design in figure 10 is aesthetically and functionally the most attractive design and shows that sound barrier can be optically transparent. The sound reducing capability of this sound barrier is more on the reflecting than on the absorbing side.

Switzerland

Plant	Installed	Type	P_0 [kWp]	Yield [kWh / kWp]	Year	Irradiation [kWh/m^2]	T Module [°C]
Aubrugg	1997	Bifacial	8.27	681	1998 / 01	1,202	26.5
Wallisellen	1998	Zig - Zag	9.65	497	1999 / 01	872	43.9
Bruettisellen	2000	Cassettes	8.2	446	2000 / 01	730	34.8

Table 4: Three 10 kWp pilot plants in Switzerland.

Two of Swiss plants are located at different locations along motorways and one plant along the railway in the Zurich region.

8kWp Wallisellen, CHE

The plant Zurich Wallisellen uses zig – zag technology and 45 mini inverters. This PVNB is a combination of sound reflection and sound absorption.

Figure 11: Zurich Wallisellen with zig – zag technology.

8kWp Bruettisellen, CHE

The plant Zurich Bruettisellen uses vertical cassettes technology and one single inverter. This PVNB is a combination of sound reflection and sound absorption.

Figure 12: Zurich Bruettisellen with vertical cassettes technology.

Innovation

8kWp Aubrugg, CHE

The 8 kWp plant Aubrugg is located near Zurich on a north-south motorway flyover and is the world first PVNB bifacial plant [5]. The modules are ASE-bifacial prototypes and are sound reflecting. One side is exposed to the morning sun and the other to afternoon sun. In theory the annual yield should be equal or more than the yield of a south-facing array. Due to the manufacturing process the B-side has a slightly lower efficiency. The annual performance results are therefore a bit lower than expected.

Figure 13: Bifacial Zurich Aubrugg with bifacial technology.

The three sisters plants in figure 11, 12 and 13 are the corresponding three R&D projects of the international design competition build an operated in Switzerland. The plant Wallisellen in figure 11 is the first PVNB application along a railway line. The question of electro-magnetic interference of the railway and the inverter was studied and proved not to be an issue. The plant Bruettisellen in figure 12 is the first PVNB application using thin film module technology. The plant Aubrugg in figure 12 is the world first PV plant using bifacial prototype cells along a north-south motorway. For a proper interaction of the inverter in with the bifacial modules special adjustments of MPP-taking feature of the inverter was necessary. The bifacial PV technology will expand the possibility of PV on sound barriers by a great extend.

Conclusions

Energy Potential
With a technical potential of 680 GWh per annum PV on sound barriers in central Europe could be a major contributor to the growing green energy market. Existing or future legislation on sound protection from motorways and railways in the individual countries could enable a cost-reducing factor for PVNB. PV on sound barriers does not require additional land resources and the costs for the mounting structures can be shared between the PV system and the sound barrier. Various technologies are already implemented and tested. If implemented on a large scale the bifacial technology could extend the energy potential of PVNB ever further.

Design considerations
The glass surface of a PV module can only be applied for the reflection of the sound. In situation where absorption of sound is required a cassette or a zic-zac model has to be applied and a combination of sound reflection and sound absorption is possible. Because PV cells operate most efficiently at lower temperatures great care should be taken in the design of sound absorption cassettes to allow sufficient cooling of the PV modules. In layered or zic-zag arrangements the layout of the modules has to be in such a way that no shading can occur at any time. Dirt from the motorway can have a negative impact on the performance if the modules are mounted to low and near the surface of the road.

Cooperation
PVNB requires a close cooperation between sound- and PV experts, as well as a cooperation of the road authorities and the financiers of the PV system. To achieve realistic cost reduction for the PV part of the project integrated systems are to be preferred to retrofit systems. With fully integrated PVNB systems a clear understanding of the cost substution should be aimed for. In an ideal situation the noise barrier and the PV plant should be planed and realised at the same time as a singe project.

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