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# GIS based Forest Biomass Exploitation for Energy Supply in the Northern Black Forest Region

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**Keywords**: remote sensing, biomass exploitation, wood energy potential, renewable energy, Geo Information System (GIS)

**Zusammenfassung:** *Entwicklung einer GIS-Anwendung zur Berechnung des Waldenergie-Holzpotenzials auf Basis von Forsteinrichtungs-Daten.* Ziel der vorliegenden Studie ist die Entwicklung einer GIS-basierten Anwendung zur Modellierung des theoretischen Waldenergie-Holzpotenzials im Nordschwarzwald. Durch den Einsatz von Forsteinrichtungsdaten auf Bestandesflächenniveau wurde dabei eine hohe thematische und räumliche Auflösung erreicht.

Forstliche Waldbewirtschaftung konzentriert sich in erster Linie auf die Produktion von hochwertigem Stammholz. Die dabei anfallenden Reststoffe und minderwertige Hölzer können energetisch genutzt werden.

Im GIS wurden vorhandene Forsteinrichtungsdaten und ATKIS Daten zusammengeführt, bearbeitet und analysiert. Die verfügbaren Menge an Waldrestholz und Durchforstungsholz, ihre räumliche Verteilung, die Kosten für Mobilisierung und Transport zum Heiz(kraft)werk werden berechnet und als Potenzialkurven und Karten dargestellt.

Die entwickelte VBA-Anwendung ist flexibel konzipiert und kann beispielsweise bei der Standortwahl von Heiz(kraft)werken eingesetzt werden.

Exemplarisch werden die Ergebnisse für den Forstamtsbezirk Bad Herrenalb dargestellt.

**Summary:** A GIS based application for calculating wood energy potential was developed taking into account economical and technical aspects. *Where*, *how much* and *at which price* forest biomass can be utilized for energy purposes are questions to be answered in this study.

A regionalized approach is achieved by using detailed inventory and forestry planning data of public forests supplied by the *Landesforstverwaltung Baden-Württemberg* (state forest administration).

Quantities of forest thinning wood and residual wood are, in their capacities as disposable energy resources, calculated for forest stands. Their production and mobilizing costs are integral parts of the model and can be altered individually by the user. Results are presented as supply curves and maps – delivering information on the pricing and the location of energy wood.

The application is applied and tested in a study region in the densely wooded northern Black Forest, within the borders of the *Regionalverband Nordschwarzwald* (regional planning authorities).

The developed routine supports local decision makers in planning of locations for new block heat and power plants. Furthermore it provides useful operational resource information for individual forest stands.

In comparison to similar GIS based studies dealing with biomass exploitation, this project aims at very high resolution regarding content as well as spatial and topological information.

## 1 Introduction

The Federal Government of Germany encourages the usage of renewable energies as primary energy resource. The goal is an increase of their shares on the total amount of used primary energy from current approximately 3% to 12.5% in the year 2010

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and finally to at least 20% in the year 2020. To this end, on 1st of August 2004 the revised Renewable Energy Law (Erneuerbare-Energien-Gesetz/EEG) became effective. This amending law enhances the conditions for biomass energy production (PONATH 2004). In coming years, the production of heating energy derived from biomass will be supported more strongly (DÜRRSCHMIDT et al. 2004).

Due to forestry practice in arboreous regions like the Black Forest in Baden-Württemberg, biomass in form of forest residues and thinning wood is disposable and available for energy production (SIGMUND & FROMMHERZ 2003).

The aim of this study is to develop a repeatable, transferable method for the modeling of forest energy wood potential on a regional level. By contrast similar previous studies are mostly missing a regionalized approach (e. g. HASCHKE 1998, KALTSCHMITT & HARTMANN 2001).

In cooperation with the *Landesforstverwaltung Baden-Württemberg* and the *Regionalverband Nordschwarzwald*, a GIS based application for forest biomass exploitation was designed. This application calculates the theoretical potential of energy wood. The results are presented in form of supply curves, taking into account economical and technical constraints.

The study region is the expanded district of the *Regionalverband Nordschwarzwald*, including the administrative districts of Calw, Freudenstadt, Enzkreis as well as the city of Pforzheim. A case study applied to the forestry district of Bad Herrenalb is presented (Fig. 1) in this paper.

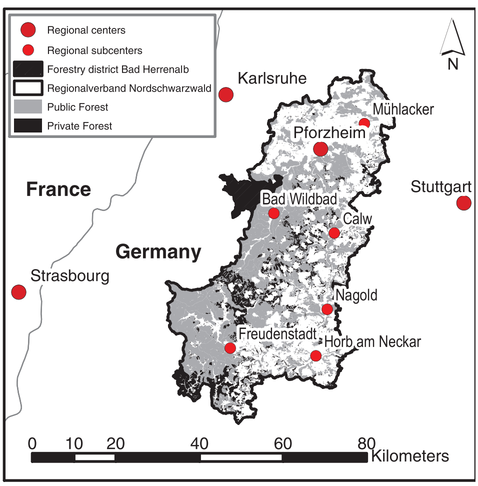


**Fig. 1:** Area of the *Regionalverband Nordschwarzwald* and the forestry district of Bad Herrenalb.

## 2 Methodology

### 2.1 *Data description*

#### *Forest inventory data*

For the regionalized approach detailed forest inventory data (*Forsteinrichtungsdaten*) were employed. Assessed only every ten years, the data used in the case study represent the characterization of the forest district of Bad Herrenalb and its operational objectives set in 2002.

These data describe each forest stand concerning e. g. age, tree species, coverage and growth classes. For each forest stand there is a maximum of three age classes. Each age class can have a maximum number of three different tree species. Each of these tree species is further specified into their relative fraction based on their canopy (Tab. 1).

Forest stands are digitised and were supplied by the *Landesforstverwaltung* as vector data, respectively polygon shapes (ESRI Format), including the quoted attributes.

**Tab. 1:** Example for the structure of the forest inventory data used in this study describing a forest stand in terms of GIS.

| Age (years) | Timber volume (Ster/ha) | Tree species | Relative fraction | Growth class |
|---|---|---|---|---|
| 30 | 120 | Fir<br>Spruce<br>Beech | 70%<br>20%<br>10% | 11<br>12<br>7 |
| 60 | 200 | Spruce<br>Fir<br>Beech | 50%<br>40%<br>10% | 10<br>11<br>7 |
| 100 | 450 | Fir<br>Spruce | 70%<br>30% | 12<br>12 |

The forest planning data consist of the amounts of to-be harvested timber for each forest stand over a ten-year period. They are part of the forest inventory data and are extracted from a database, which is administered by the *Zentrale EDV Sachbearbeitung* (centre of data processing) of the *Landesforstverwaltung*. The files were delivered in MS Access format.

### *Additional geodata*

Other data used are from the ATKIS (Amtliches Topographisches-Kartographisches Informationssystem), more precisely the DEM (Digital Elevation Model) with a 50 m grid and the DLM25 BW (Digital Landscape Model of Baden-Württemberg, scale 1 : 25,000). Additional raster data (TÜK 200, Topographische Übersichtskarte 1 : 200,000) were used.

These geodata are available from the *Landesvermessungsamt Baden-Württemberg*, but were supplied for the case study by the *Regionalverband Nordschwarzwald.*

### *Data handling*

Some data preparations were necessary like assigning the forest inventory data to the forest stands based on an altered database key. Combining the data in ArcGIS made further GIS analyses possible. Typical accomplished operations for the case study in ArcGIS include merging, clipping and dissolving, joining tables and adding newly calculated fields.

## 2.2 *Calculation of the theoretical potential*

### *Definitions*

German forestry mainly focuses on harvesting high-quality timber wood. Still there are considerable amounts of residuals, which are available for energy production. These "left-overs" are **thinning wood** and **residual wood** (Fig. 2).

**Thinning wood** evolves from tending timber stands and can be fully used for energy

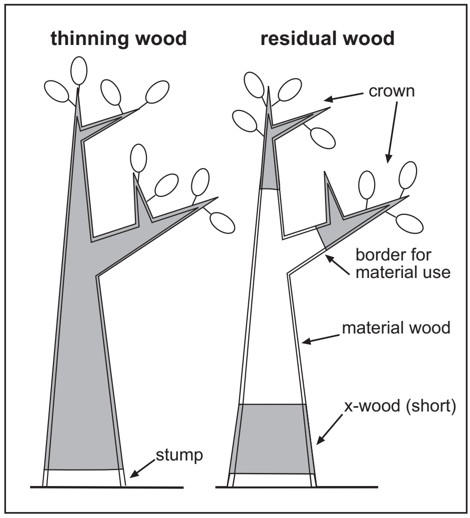


**Fig. 2:** Thinning and residual wood – available biomass components for energetic use (grey) (DIETER & ENGLERT 2001, modified).

purposes. For differentiation between thinning and material wood the breast height diameter (BHD) is used. The BHD is the diameter of a tree in 1.30 m above mineral ground (KRAMER & AKÇA 1995). Typical BHD border values are between 15 cm and 25 cm. In this study, this border is called the upper BHD limit. In the application selectable values for the upper BHD are: 15 cm, 20 cm, 25 cm and 30 cm (Fig. 3).

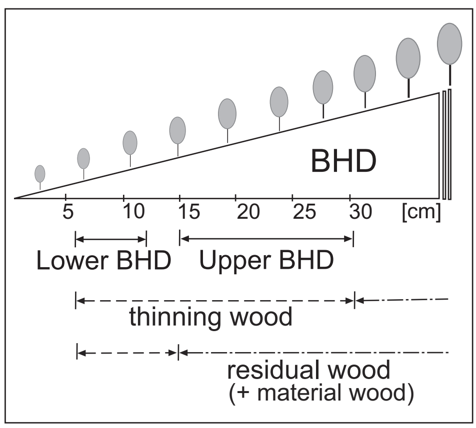


**Fig. 3:** Dimensions of the BHDs used in the application and the correlation between thinning, residual and material wood.

The other applicable borderline of thinning wood is the lower BHD limit. Selectable values in the application lie between 6 cm and 12 cm. This is the lowest BHD possible where processing is still economical. This depends on the species and the transport distances (Fig. 3) (Dieter & Englert 2001).

As a simplified approach for this study, an average BHD was calculated for the dominating tree species of each age class. This BHD was transferred to other species in the same age class of the corresponding forest stand.

**Residual wood** consists basically of worthless parts of a cut tree, like already prepared but discolouring wood (x-wood) or the crown with benches of a diameter less than 7 cm (border of material use) (Figs 2 and 3).

**Materialwood** can be divided into stacked wood, industry wood and log wood. Their shares depend on the BHD and the species, e. g. a tree with a large BHD has more shares of log wood and less of the others. Usually it is not used for energy purposes (Figs 2 and 3).

Foliage should stay in the forest for the sustainability of the ecosystem.

### Data calculations

After defining the disposable energy wood, some data calculations were necessary. The whole amount of the available wood for the modeling of the theoretical wood energy potential had to be calculated out of

(1) *to-be harvested timber* per age classes and per species based on forest planning data
(2) *twigs and benches* (diameter less than 7 cm) for (1) based on Kramer & Krüger (1981)
(3) *the different energetic value* of the tree species based on Dieter & Englert (2001).

The development of the application demanded further calculations like

(4) *an average BHD* for the main tree species of each age class based on forestry harvesting tables (*Ertragstafeln*, LFV 1993)
(5) *estimations of the usages of wood stock* depending on BHD and species based on forestry sort tables (*Bestandessortentafeln*, LFV 1993).

To accomplish (1), each forest stand's planning data are assigned to its different age classes and tree species proportionally to their relative fractions.

Planning data only quote logs with a BHD larger than 7 cm (including bark) (2). So twigs and benches are not accounted for. Therefore increments for these additional energy woods had to be calculated based on empirical studies by Kramer & Krüger 1981. Increments depend on species and age class.

According to Dieter & Englert (2001), the different energy value of the four main species (fir, beech, pine, oak) is also considered in the modeling (3).

Because the BHD is not specified in the planning data (4), an average BHD had to be calculated for each forest stand's age class as a function of tree species, age and growth class on the basis of forestry harvesting tables (*Ertragstafeln*, LFV 1993). The growth class is an empirically determined factor that accounts for natural ecological conditions.

For volume calculations of residual wood, it is important to differentiate the usages of the wood stock (e. g. x-wood, stacked wood, industry wood, log wood). The forestry sorting tables (*Bestandessortentafeln,* LFV 1993) split the usages depending on BHD and species. Data of stacked and industry wood were included in the application. Integrating these types of material wood allow operators of the application to chose additional energy wood resources.

According to Dieter & Englert (2001), obtained amounts of energy wood as solid cubic meter were converted into dry weight ($t_{atro}$) respectively into energy value (MWh).

All calculations were carried out in ArcGIS.

## 2.3 Integration of mobilization costs

Mobilization costs per energy unit (MWh) depend mainly on characteristics of the forest stands (BHD, tree species, etc.),

- applicability of automated harvesting methods,
- chipping of wood chips,
- expansion of regular road and logging road networks.

Apart from the characteristics of the forest stand, the grade of automation of the harvesting method is crucial for the production costs. Basically, there are three different harvesting methods (BUNK 2002):

(1) *Manually operated*: felling trees with chain saws, further manual preparations like trimming,
(2) *Partly automated*: cutting trees with chain saw, felling and transport supported by winches,
(3) *Highly automated*: wood chip harvester, felling, transport and chipping of wood all inclusive.

(2) and (3) are often used in combination. Due to economical reasons only methods (2) and (3) are used by public forestry. Private forests are often harvested manually.

Energy wood in form of wood chips is favourable especially for fully automated plants. Because of their fluid behaviour, a continuous conveyance can be guaranteed. Their handling is convenient and wood with low diameters can be used, too. Processing of wood chips is assumed to take place on the nearest forest road close to the harvesting location.

Production costs for wood chips from thinning wood are depending on the BHD, and the grade of automation as shown in Fig. 4. Numbers are based on empirical studies (DIETER & ENGLERT 2001, WITTKOPF et al. 2003).

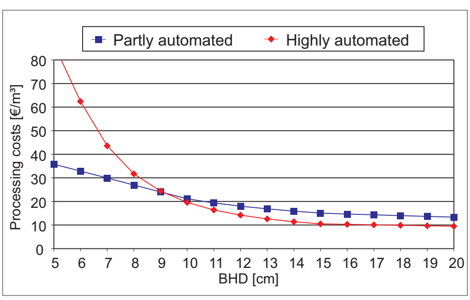


**Fig. 4:** Wood chip production costs for thinning wood (DIETER & ENGLERT 2001, modified).

The missing of production cost data for residual wood required estimations. These estimated values can be altered in the application. Steepness of terrain and BHD are limiting factors for highly automated harvesters.

In the GIS, the DEM was used to calculate the slope and reclassify three slope classes (0%–30%, 30%–60%, >60%). These were converted to vector data and assigned to the forest stand polygons.

Depending on slope class, BHD and production, different costs are assigned to each forest stand (Tab. 2).

**Tab. 2:** Wood chip production and corresponding costs (DIETER & ENGLERT 2001, modified).

| Slope [%] | Energy wood | BHD [cm] | Harvest/ chipping | assigned costs |
|---|---|---|---|---|
| <30 | Thinning wood | | Highly automated | depending on BHD, (Fig. 4) |
| | Residual wood | <35 | Highly automated | 9.44 €/m³ (estimated) |
| | | >35 | Partly automated | average BHD = 10 cm (estimated) |
| 30–60 | Thinning wood | | Partly automated | depending on BHD, (Fig. 4) |
| | Residual wood | | Partly automated | average BHD = 10 cm (estimated) |
| >60 | No harvesting possible | | | |

## 2.3 *Transport modeling*

In the transport modeling it is assumed that wood chips are getting prepared at the logging road or skid road close to the harvesting area. Depending on the distance the wood chips are transported to the plant either on trucks with containers or on tractors with trailer.

The following costs are assigned to the application:

**Tab. 3:** Transporting and handling costs for wood chips.

| Transport | Loading/Unloading costs | Transport Costs (per km) |
|---|---|---|
| Tractor with trailer | 0.75 €/MWh | 0.25 €/MWh |
| Container truck | 1.25 €/MWh | 0.12 €/MWh |

According to these numbers, it is cheaper using a tractor instead of a truck for distances less than four kilometres. Transporting wood chips on tractors at shorter distances can be economical (WITTKOPF et al. 2003).

ATKIS data provided detailed information on the logging roads and streets. Skid roads are not yet available as vector data of the *Landesforstverwaltung*. A geometrical network was created in a geodatabase. The closest road network node was allocated to each forest stand.

Two fictitious plant sites in the study area are chosen and shortest path calculations from each forest stand were calculated based on a simplified Dijkstra algorithm (ESRI 2001). Each forest stands polygon received additional attributes: the shortest distances to the plant sites. Depending on these distances, the cheapest transport costs were assigned.

User forms are programmed in ArcGIS with VBA.

## 3 Results and discussion

Executing the ArcGIS based application for the forest district of Bad Herrenalb, will deliver results in form of supply curves (e. g. Fig. 5). These show the primary energy potential of the biomass resource in function of its market price. The total amount of the calculated theoretical potential (2.2), the assigned production (2.3) and the transportation costs (2.4) cause level and trend of the supply curves.

By choosing provided options, users can model different scenarios like (Fig. 3)

(1) variation of the lower BHD,
(2) variation of the upper BHD (Fig. 5),
(3) accessing additional energy resources: + stacked wood, + industry wood,
(4) including transport costs,
(5) considering the tree species, etc.

In (1) and (2) thinning wood, residual wood (Fig. 3) and stacked wood are considered as energy wood. Depending on the BHD, each has different shares on the energy potential. In (2) less residuals for energy purposes are compensated by larger amounts of thinning wood (Fig. 3).

The following supply curves (Fig. 5) show scenario (2) with a constant lower BHD at 8 cm and a varying upper BHD. It does exclude transport costs.

Raising the upper BHD to 25 cm compared to lower BHD's at 15 cm or 20 cm provides a strong increase of the disposable potential. At 14 €/MWh nearly half of the primary energy potential is accounted for. The larger gap between 20 cm and 25 cm is explained by the increases of the volume or mass of a tree compared to its diameter. The supply curves show that competitive usage of the wood – for energy or material purposes – is severe between 20 cm and 25 cm BHD limitations.

Displaying results as maps like in Fig. 6 is another option. Wood chip processing costs for the dominating age class of each forest stand are shown.

Modeling transport costs needed to install two fictitious plant sites (Dobel and Bernbach) (Fig. 6) in the study region. Potential consumers for the produced heat and/or electric power are located close by.

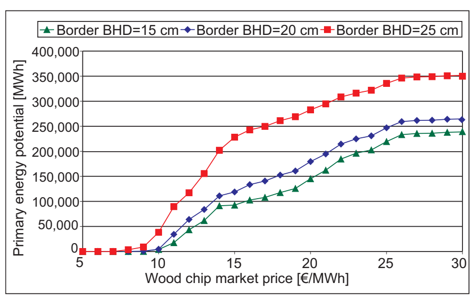


**Fig. 5:** Supply curves with varying upper BHD, scenario (2).

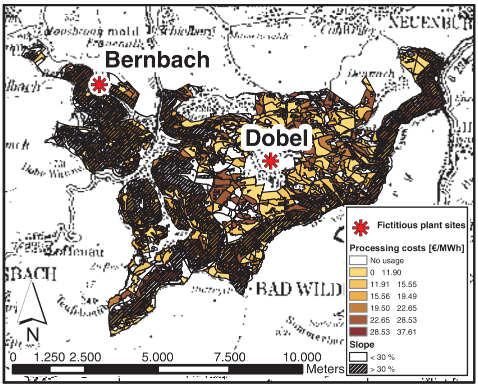


**Fig. 6:** Wood chip processing costs for the forestry district of Bad Herrenalb.

Only forest stands of the forestry district of Bad Herrenalb were considered in the modelling. Distances from forest respectively their closest network node to each plant are calculated (2.4). To simplify the modeling there is no competition between the plants. Therefore, each can access the complete available energy wood potential. Average distances from forest stands i. e. wood chip production sites to Bernbach plant are 10,311 km and to Dobel plant 6,079 km.

Especially when market prices are low, greater transport distances have a bad impact on the cost-effectiveness of the unfavourable located Bernbach plant (Fig. 7).

Using assumed cost parameters, supply costs for forest wood chips exceed those of other wood resources like wood chips from landscape conservation measures. The lowest calculated price for the production

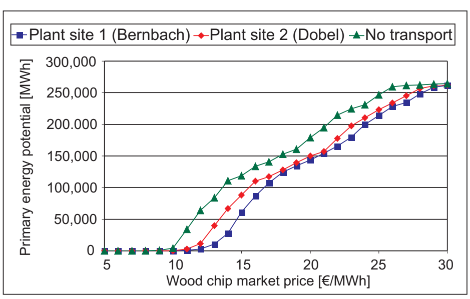


**Fig. 7:** Supply curves including transport modeling compared to a supply curve only considering production costs.

of 1 MWh out of energy wood in this study is approximately 9 € (excluding transport) in comparison to 7.5 €/MWh all inclusive for energy wood out of landscape conservation measures (Bunk 2002, Sigmund & Frommherz 2003).

The developed GIS application can assist planning authorities and decision makers in locating future plant sites. It can also be employed in the operational business of wood chip production because of the multi criteria based identification for forest stands.

Because of the complexity of the subject and missing data some simplifying assumptions were necessary: The amount of uncertainty added through these assumptions is difficult to quantify.

## 4 Conclusions

The particularity of this study is the very detailed, regionalized approach accomplished through the availability of different forestry data, their consolidation and integration into the GIS. The required cross data analysis for the economic production of wood chips, which depends on several spatial criteria, can only be handled with GIS.

The study shows the potential for energy wood in the northern Black Forest region.

Further actions should concentrate on adding data of privately owned forests, integrating other wood energy resources and consumer data.

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## References

Bunk, H., 2002: Holz-Energiefibel, Holzenergienutzung, Technik, Planung und Genehmigung. – 98 S., Wirtschaftsministerium Baden-Württemberg (Hrsg.), Stuttgart.

Dieter, M. & Englert, H., 2001: Abschätzungen des Rohholzpotenzials für die energetische

Nutzung in der Bundesrepublik Deutschland. – 40 S., Arbeitsbericht, Institut für Ökonomie, Bundesforschungsanstalt für Forst und Holzwirtschaft, Universität Hamburg. (24. 09. 2004)

DÜRRSCHMIDT, W., ZIMMERMANN, G. & LIEBING, A., 2004: Erneuerbare Energien, Innovationen in die Zukunft. – 128 S., Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Hrsg.), Berlin.

ESRI, 2001: Exploring ArcObjects. – 1305 S., ESRI Press, Redlands, California.

HASCHKE, P., 1998: Forstliche Energieholzpotenziale in Deutschland und Aspekte ihrer zukünftigen Nutzung. – Holz-Zentralblatt **53:** 805–806.

KALTSCHMITT, M. & HARTMANN, H., 2001: Energie aus Biomasse, Grundlagen, Techniken und Verfahren. – 770 S., Springer, Berlin.

KRAMER, H. & AKÇA, A., 1995: Leitfaden zur Waldmesslehre. – 3., erw. Aufl., 298 S., Sauerländer's, Frankfurt/M..

KRAMER, H. & KRÜGER, H.H., 1981: Vorrat und Nutzungsmöglichkeiten forstlicher Biomasse in der Bundesrepublik Deutschland. – Der Forst- und Holzwirt **36:** 33–37.

Landesforstverwaltung Baden-Württemberg (LFV), 1993: Hilfstabellen für die Forsteinrichtung. – 188 S., Ministerium für Ernährung und Ländlicher Raum Baden-Württemberg (Hrsg.), Stuttgart.

PONATH, J., 2004: Novelle zum Erneuerbaren-Energien-Gesetz. – B&B Agrar **04** (3): 1–2.

SIGMUND, V. & FROMMHERZ, J., 2003: Herleitung des verfügbaren Waldenergieholzpotenzials in Baden-Württemberg auf Basis der Forsteinrichtungsplanung. – Unveröffentlichter Abschlussbericht i. A. d. Forstdirektion Freiburg.

WITTKOPF, S., HÖMER, U. & FELLER, S., 2003: Bereitstellungsverfahren für Waldhackschnitzel – Leistungen, Kosten, Rahmenbedingungen. – 80 S., Berichte aus der LWF Nr. 21.

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