Forest biomass mapping with LiDAR data, GIS accessibility analysis and economical model: a case study in the canton of Valais (Switzerland)

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Topic: 1 Biomass resources - Sub topic: 1.1 Biomass potentials and biomass mobilisation

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Summary

In mountainous areas, forest resources are spatially heterogeneous, difficult to quantify and harvest because of topographical constraints. In the framework of the PlanEter project, we implemented a case study with the objective to map the quantity and mobilisation cost of fuelwood in six communes (600 km^2), thanks to LiDAR remote sensing data, a GIS-based accessibility model and an economical model.

The main challenge was to design an easily reproducible methodology for larger application, thanks to the use of available public data as inputs. Wood growing stock was mapped at 20 m resolution with models calibrated with national LiDAR and forest inventory data. The technical accessibility of forests to common machinery was mapped with the GIS-based model Sylvaccess using national digital terrain and landscape models. Local forest statistics and cover maps were used to derive the annual timber and fuelwood potential.

The results are used at two different levels. For strategic planning, a simplified model of forest management is used to map the annual timber and fuelwood harvest and the corresponding costs, depending on the technical accessibility and forest structure. For operational planning, resource and accessibility information are used as inputs along with expert information, into the detailed model CalCouFor for cost calculation of harvesting, yarding, transport, storage and chipping operations.

This case study shows that it is possible to bridge the gap between regional forest statistics and field level analysis through the use of existing datasets. Additional remote sensing information could provide information about annual forest increment and species which would improve the model of forest management, taking into account other socio-economic services provided by forests. It would then be possible to map the effects of various factors (energy price, labour costs, public subsidies) on forest biomass mobilisation.

Purpose of the work

In Alpine countries such as Switzerland and France, the forest growing stock in mountainous areas is continuously increasing, because of agricultural decline and increasing labour costs. Meanwhile, topography hampers the harvesting of forests, which are very heterogeneous due to growing conditions and limited possibilities of human intervention. An accurate mapping of standing volume and accessibility, as well as precise costs evaluation, are thus a pre-requisite for an efficient mobilisation of mountain woody biomass.

Airborne laser scanning, or LiDAR, is a remote sensing technique which has proven its usefulness for mapping forest structure, and is now available for entire countries such as Switzerland. However, the implementation of a forest mapping workflow based on available data at a regional level still remains a challenge.

High resolution digital terrain models can be calculated from LiDAR data. Thanks to the improvement in processing power and geographical information software, it is now possible to simulate the operating mode of yarding machines at a technically appropriate resolution and at operationally relevant scale.

The objective of this case study is to combine both tools to map the quantity and cost of fuelwood. Special emphasis is set on :

- the possibility of large-area implementation of the workflow by making use of available public data.
- the identification of limitations regarding the accuracy of the results and the relevance of modelling hypotheses regarding the applications at two levels : strategic and operational planning.

The study area includes six communes (600 km^2) in the canton of Valais, Switzerland.

Operational planning is developed in a way to serve as a user-friendly tool, “CalCouFor”, available for forestry actors to precisely evaluate site-specific timber exploitation costs from harvesting to fuelwood transformation, including all intermediate steps (transport, storage and chipping).

Approach

For **forest structure** mapping, estimation models are built based on LiDAR data and field references, according the so-called area-based method (White *et al.*, 2013). LiDAR data is available from a national acquisition (Swisstopo) and forest plots from the national forest inventory are used. The main target variable is standing volume, but other parameters such as mean diameter are also estimated as they are used for subsequent cost calculation. Corresponding maps are computed at 20 m resolution.

Forest accessibility is mapped with Sylvaccess (Dupire *et al.*, 2015a, 2015b), which simulates the operating mode of skidder and cable crane. Simulation parameters are chosen according to local practices. Input data are the digital terrain model, the road network and anthropic obstacles. Those data are available from local authorities and from Swisstopo. The outputs are maps of accessible areas with corresponding technical criteria relevant to each mode.

For strategic planning, wood energy is then calculated based on a harvesting ratio and conversion factors depending on the softwood/hardwood stands mapped by local authorities. The corresponding harvesting and yarding costs are computed based on a simplified management model. Based on priority rules regarding the yarding mode, the technical criteria are used with simplified cost grids to map the mobilisation cost.

For operational planning, specific costs related to wood exploitation are modelled based on the already existing tool HeProMo (Frutig *et al.*, 2015) estimating temporal and financial harvesting and yarding processes. Different modules are further developed in the scope of this project to estimate downstream processes like transport, chipping and storage. A conversion energy module is then able to evaluate total cost per kWh. This unique tool is developed in a way that enables the user to use each module independently or linked them together in any order.

Scientific innovation and relevance

Numerous studies have been published regarding the methods for forest mapping with airborne laser scanning. However, there is little knowledge about the implementation at regional scale with existing data, which are not specifically acquired for this purpose.

The use of forest structure information in the mapping of forest accessibility is important in mountain areas, e.g. cable yarding is only relevant if a sufficient volume is available along the whole line, whereas skidder operations are spatially independent. Combining both tools for yarding mode selection and spatially-explicit cost calculation is of high added-value for forest managers.

In addition, having a unique and comprehensive tool dedicated to forestry actors evaluating fuelwood exploitation costs will facilitate and encourage its mobilisation knowing its site-specific financial weight.

Conclusion and results

Cross-validation of forest standing volume models shows an error at the pixel level of around 40%, which is mainly due to spatial and temporal shifts between the airborne and field data acquisitions. Despite this error, local forest managers acknowledged that spatial variation in the forest structure was correctly rendered at large scale. The mean error for large areas is close to zero which makes it relevant for strategic planning purposes.

Limits and perspectives regarding the combination of forest structure and accessibility for cost calculation were identified. A deeper integration is required, but management decisions will be difficult to model due to the absence of information regarding local operational and administrative criteria, such as ecological and economic constraints (e.g. available forestry machines or local timber market). Spatially-explicit information is also required regarding annual net increment and wood quality and species in order to better estimate the annual fuelwood harvest. Such information could be derived from other remote sensing data, e.g. aerial time-series and multispectral images.

This case-study is a first step toward the mapping of forest biomass at regional level with operational relevance. Workflow outputs allow the calculation of regional statistics and also to identify priority areas for mobilisation, where accurate costs can be estimated thanks to a comprehensive, operational tool. This method is on the way to be implemented on the entire territory of the canton of Valais (5’224 km^2).

The workflow can be further improved by optimising and integrating new remote sensing inputs in order to be able to add details from the operational model into the strategic one. Refining the model of forest management will also allow to map the spatial effects of external factors (timber price, labour costs, public subsidies) on the forest biomass mobilisation.

References

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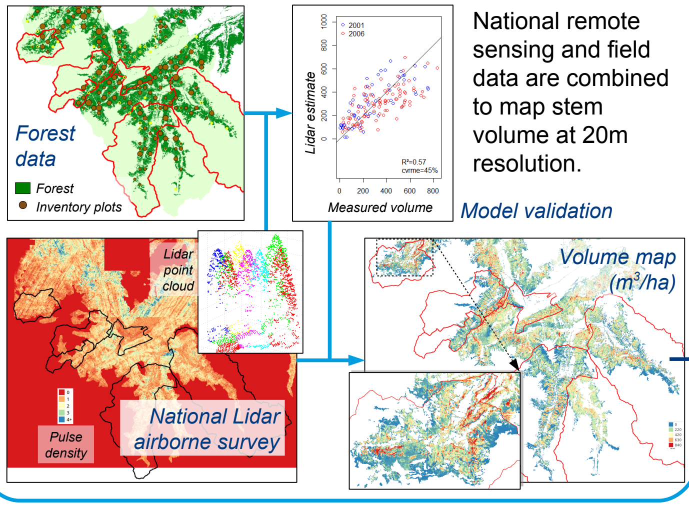
In mountainous areas, forest resources are heterogeneous and difficult to quantify. A methodology based on Lidar and GIS is tested for mapping forest resources and accessibility. Results are used for strategical planning (global annual fuelwood harvest and costs) and operationnal planning with the tool CalCouFor which integrates expert information for cost calculation from harvesting to energy conversion.

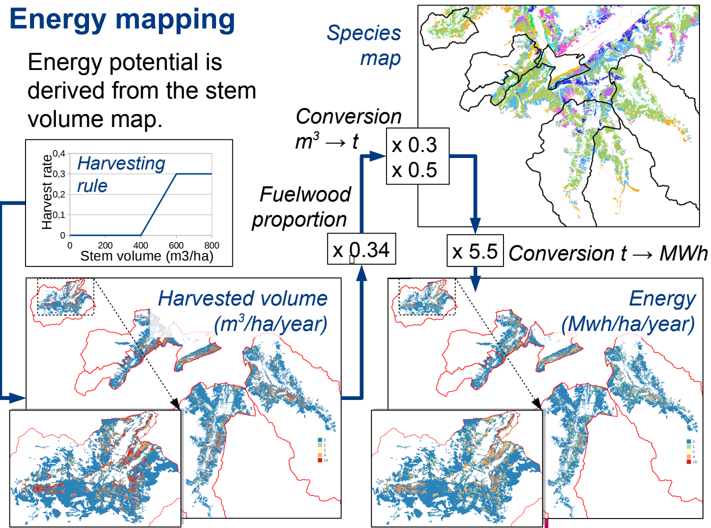
Stem volume mapping

National remote sensing and field data are combined to map stem volume at 20m resolution.



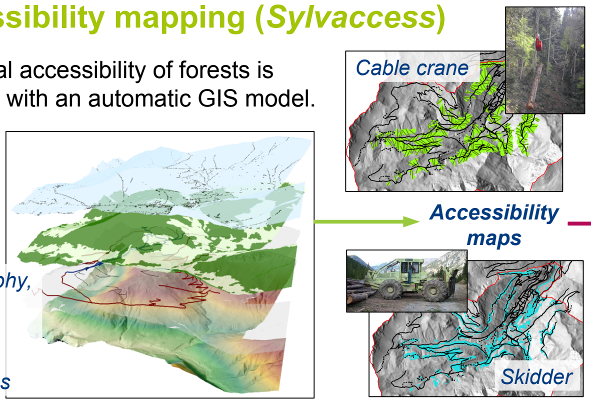
Energy mapping

Energy potential is derived from the stem volume map.



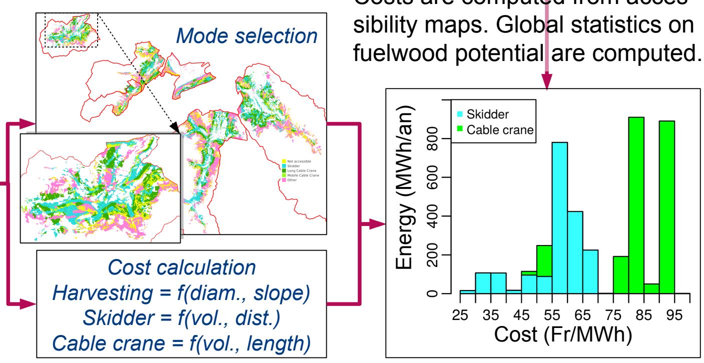
Accessibility mapping (*Sylvaccess*)

Technical accessibility of forests is mapped with an automatic GIS model.



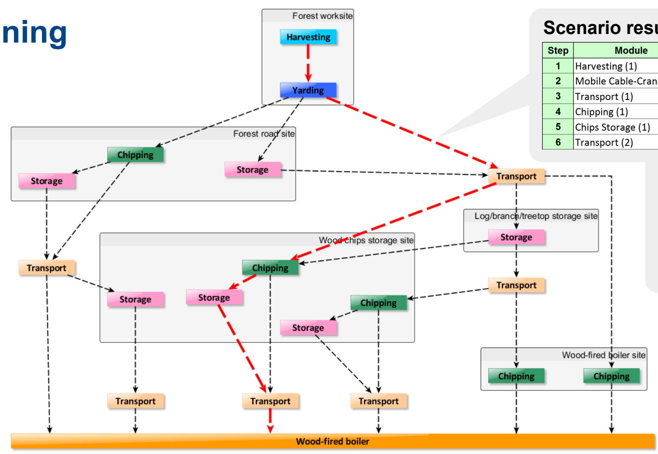
Cost calculation

Costs are computed from accessibility maps. Global statistics on fuelwood potential are computed.



Cost calculation for operationnal planning (CalCouFor)

For operational planning, resource and accessibility information are used as inputs along with expert information, into the detailed model CalCouFor for cost calculation of harvesting, yarding, transport, storage and chipping operations.
Specific costs related to wood exploitation are modelled based on the already existing tool HeProMo (Frutig *et al.*, 2015) estimating temporal and financial harvesting and yarding processes. Different modules were further developed in the scope of this project to estimate downstream processes like transport, chipping and storage. A conversion energy module is then able to evaluate total cost per kWh.
This unique tool is developed in a way that enables the user to use each module independently or linked them together in any order (scenario).



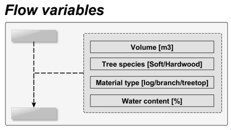
Scenario results example

Step	Module	Volume	Unit	€/m3	€
1	Harvesting (1)	300	[m3 solid wood]	59.9	17'980
2	Mobile Cable-Crane (1)	300	[m3 solid wood]	79.4	23'809
3	Transport (1)	300	[m3 solid wood]	27.0	8'113
4	Chipping (1)	840	[m3 wood chips]	5.0	4'200
5	Chips Storage (1)	840	[m3 wood chips]	1.5	1'270
6	Transport (2)	840	[m3 wood chips]	4.2	3'557

		Unit
Total volume	840	[m3 wood chips]
Total cost	58'929	[€]
Cost per volume	70.15	[€/m3 wood chips]

Energy	569'678	[kWh]
Cost per kWh	10.34	[cents/kWh]

Flow variables



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