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Fuel for debating ancient economies. Calculating wood consumption at urban scale in Roman Imperial times

Ellen Janssen [a], Jeroen Poblome [b], Johan Claeys [b], Vincent Kint [a], Patrick Degryse [a], Elena Marinova [a], Bart Muys [a,*]

[a] Department of Earth and Environmental Sciences, University of Leuven, Celestijnenlaan 200E Box 2411, 3001 Leuven, Belgium
[b] Sagalassos Archaeological Research Project, University of Leuven, Blijde Inkomststraat 21 Box 3314, 3000 Leuven, Belgium

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ABSTRACT

Estimating wood extraction rates from forests based on archaeological and historical evidence is an important step in evaluating the sustainability of past social-ecological systems. In this paper, we present a calculation tool to estimate human wood resource use for a selected location during a defined period in the past. We illustrate the method by its application to the ancient town of Sagalassos (South-west Anatolia, Turkey) during the Roman Imperial period, with a focus on pottery production and the Roman Baths. Based on archaeological data, thermodynamic formulas and calorific values, an estimation is provided of the amount of wood used within a time step of one year. Because quantitative information on ancient technology and lifestyle is rather scarce and uncertain, input values consist of ranges. In order to take this uncertainty into account, a Monte Carlo procedure is included, offering a probability distribution of possible outcomes. Our results indicate that wood consumption in 2nd century Sagalassos was quite high, with a lifestyle including frequent hot bathing, export driven pottery production and a climate that required heating during winter months. Based on the available woodland area, we conclude that the community of Sagalassos was intensively using the surrounding forests.

1. Introduction

Wood was humanity's first source of energy. Up until the industrial revolution, it was by far the most important fuel for households and crafts and was an important material for construction (Malanima, 2013). Even today, wood remains the dominant energy source for cooking for almost 40% of the world's population, albeit mainly in developing regions (OECD/IEA, 2013). Unsustainable wood harvest can lead to forest degradation, deforestation, wood shortage and a loss of forest ecosystem services such as soil protection and water regulation.

The concept of sustainability originates from forestry and was introduced in 1713 by Hans Carl von Carlowitz in his essay *Sylvicultura oeconomica*, in which he proposed the principle that only as much wood as could be regrown should be harvested. Centuries later, the Brundtland Report (1987) defined sustainable development as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*', a rather broad and vague definition. For forestry, this concept was translated into seven principles of sustainable forestry in the '*non-legally binding instrument on all types of forests*' adopted by the United Nations in 2007. These principles cover the economic, ecological and social functions of forests. In this paper, we will focus on the economic aspects of sustainability, and more specifically on the balance between wood harvest and regrowth. Estimating wood extraction rates based on archaeological evidence is clearly an important part of this analysis and is essential for evaluating the sustainability of past social-ecological systems.

Although interesting studies on energy consumption (Malanima, 2013) and deforestation (Hughes, 2011; Harris, 2013) in the Roman world do exist, they rely mainly on historical and palynological data. Kaplan et al. (2009) simulated spatial and temporal trends in anthropogenic deforestation in Europe and large parts of the Mediterranean based mainly on population density and the amount of arable land required to feed this population. However, their model fails to address deforestation caused by wood harvest, e.g. for metallurgy. Veal (2012) used ethnoarchaeological data to model the fuel consumption of Pompeii in 79 CE based on per capita wood consumption. While the method used in this study is very useful, it is difficult to take the effects of industry or public facilities in cities into account using this approach. In this paper, we present a novel calculation tool to estimate human wood consumption for a selected location during a defined period in the past. The calculations are based on archaeological data and account for the associated uncertainty of these datasets. We illustrate the method by applying it to the ancient town of Sagalassos (Southwestern Turkey) during the Roman Imperial period. We first present a conceptual overview of

Abbreviations: CV, (calorific value); SRSW, (Sagalassos red slip ware).

* Corresponding author.
E-mail address: bart.muys@kuleuven.be (B. Muys).

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our wood consumption tool and then go into more detail for the Roman Imperial Sagalassos case study.

2. The XylArch tool

2.1. Conceptual model

In order to investigate the impact of a community on the surrounding forests, we need information on both the harvest and production of wood. Wood harvest is defined as all the wood that is extracted from a certain area by humans, whether it is extracted for energy or non-energy purposes or exported to other areas. On the other hand, when wood is imported to a defined area, this is regarded as a reduction in the amount of wood harvested in that area. Wood production is defined as the amount of suitable wood that grows in a certain area. In a sustainable system, wood harvest is lower or equal to wood production within a certain area and time frame.

Wood harvest depends on the wood-based energy consumption, the amount of wood used for non-energy applications and the export and/or import of wood (Fig. 1). To estimate the amount of wood that is used for energy purposes, we first need to estimate the amount of wood-derived energy that is consumed by households (mainly for heating and cooking), public facilities (e.g. for the heating of public buildings, such as bath complexes) and craftsmanship (e.g. for pottery production, metallurgy). If we then know the energy content of the wood, we can derive the amount of wood that is needed for the estimated energy consumption.

A second important component of wood harvest is non-energy wood consumption, which can also be divided into the same major sectors: household construction and furnishing (e.g. wooden floors, doors and shutters), public facilities construction (e.g. roof construction) and handicrafts (e.g. carpentry tools).

Since the production of wood is typically expressed on an annual base, calculations of wood harvest are also done annually. This ensures that all calculations are intercomparable and that seasonal variations are included.

2.2. Energy use

2.2.1. Energy consumption

The energy consumption of past communities is calculated in separate modules for households, public facilities and craftsmanship. Since each society has its own unique characteristics, communities have their own sets of modules. This first version of the tool provides a calculation of the two main energy consumers of craftsmanship and the public sector of Sagalassos, respectively the local pottery production and the Roman Baths. The energy consumption of households is very complex and, although research is ongoing, little information relevant for our purpose is currently available. For this reason, a detailed calculation on the wood consumption of households is not yet available, but an estimate of total wood consumption based on population size is given in the discussion part of this paper.

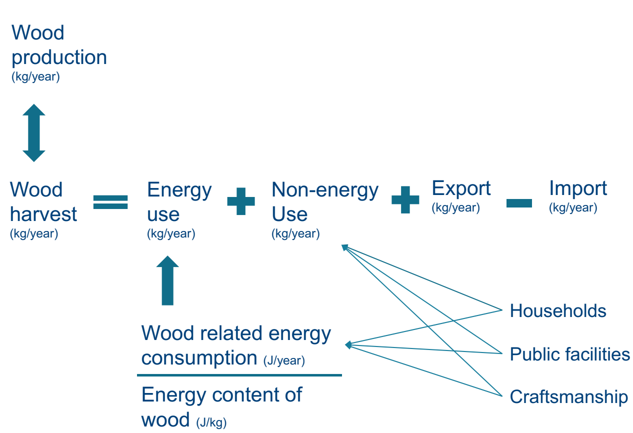

Fig. 1. Conceptual model of the XylArch tool. Only the 'Energy use' component is incorporated in the current version of the tool.

2.2.1.1. Pottery production. The amount of energy needed for pottery production can be calculated based on the amount of clay fired and the energy needed to fire this clay. The amount of fired clay can be estimated based on the number of kilns, their firing rate, the kiln load and the vessel weight (formula (1)). Please refer to Appendix A for further explanation of the variables.

$$Q = \text{kilns} \times \frac{\text{firings}}{\text{year} * \text{kiln}} \times \frac{\text{vessels}}{\text{firing}} \times \frac{\text{kg}_{\text{clay}}}{\text{vessel}} \times \frac{\text{Joule}}{\text{kg}_{\text{clay}}} \quad (1)$$

2.2.1.2. Roman bath complexes. The energy requirements of Roman bath complexes (i.e. the amount of energy needed to heat the rooms and bathwater) can be calculated based on thermodynamic formulas.

The amount of energy needed to heat the rooms or spaces can be roughly estimated using a general thermodynamic formula (formula (2)) that calculates the amount of heat that is lost through the floors, walls, ceilings and windows. Please refer to Appendix A for further explanation of the variables/parameters.

$$Q_{space} = \lambda \times A \times \frac{dT}{dl} \times t \quad (2)$$

The amount of energy needed to heat the water can also be calculated using a general thermodynamic formula (see Appendix A for further explanation):

$$Q_{water} = c \times m \times dT \times V \quad (3)$$

The total amount of energy needed for Roman bath complexes is the sum of the energy needed to heat the water and the rooms, divided by the percentage of energy that is not lost to the environment (efficiency of the system, see Appendix A for further explanation):

$$Q_{Roman\ baths} = (Q_{space} + Q_{water}) \times \frac{1}{Efficiency} \quad (4)$$

2.2.2. Energy content of wood

The energy available in wood is called the calorific value (CV) of wood, which is the amount of energy released during complete combustion of the wood. The CV is determined by the chemical composition of the wood and its moisture content. In our calculations, we will calculate the amount of oven dry wood (calculated with CV_0, i.e. CV of oven dry wood) needed yearly with the following formula:

$$Wood = Energy \times \frac{1}{CV_0} \quad (5)$$

Please refer to Appendix A for further explanation of the variables/parameters.

2.3. Non-energy use and export and import

Non-energy wood consumption is not discussed in this paper. Wood used in furniture, construction and tools, for example, lasted for many years and could often be recycled. We therefore consider its proportional consumption negligible to energy-related wood consumption, which consumed large amounts of firewood on a daily basis.

It is very difficult to archaeologically establish whether or not wood was imported or exported, let alone to calculate the amounts. The scale