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Socio-ecological Impacts of Brick Kilns in the Western Ghats: A socio-metabolic Analysis of small-scale Brick Industries in the Mumbai Metropolitan Region, Maharashtra, India

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Socio-ecological Impacts of Brick Kilns in the Western Ghats: A socio-metabolic Analysis of small-scale Brick Industries in the Mumbai Metropolitan Region, Maharashtra, India*

von

Dominik Noll

** Masterarbeit verfasst am Institut für Soziale Ökologie (IFF-Wien), Studium der Sozial- und Humanökologie. Diese Arbeit wurde von Univ.-Prof. Dr. Marina Fischer-Kowalski betreut.*

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for Kavita and Ahmed
may all their efforts
lead to a brighter future

der freie markt

so viel wie möglich und mehr.
so gross wie möglich und grösser.
so schnell wie möglich und schneller.
so lang wie möglich und länger.

mehr und wenn möglich alles.
grösser, wenn möglich am grössten.
schneller, wenn möglich am schnellsten.
länger, wenn möglich am längsten.

wieviel ist so viel wie möglich?
wieviel ist wenn möglich alles?
wieviel möglichkeiten gibt es?
wieviel wirklichkeiten bleiben?

Peter Fahr

Abstract

The production of burnt clay bricks is a large industry in India dominated by small-scale enterprises, using mainly surface soil as raw material. The present study analyses a cluster of nine brick kilns in the Mumbai Metropolitan Region by applying the material and energy flow analysis (MEFA) to the brick industry on a local level. Soil and water were identified as the two main materials in terms of quantity, while significant amounts of sand, black coal, rice husk, salt, diesel and petrol are also used. The energy for the entire production process is provided by black coal, rice husk, diesel, petrol and human labour. In this study estimations for the material and energy consumption per produced tonne of bricks are presented and it is shown, that the specific energy consumption of the brick industry in the study area is comparatively low. The brick consumption of a typical 20-floor apartment building in the MMR was estimated, translating to 0,5 ha of disturbed agricultural area. The regional, social and economic context of the brick industry in the region was explored through interviews, showing that people perceive the soil depletion for brick production as highly unsustainable and as a threat to food production. A mineralogical analysis of green brick samples from the study area was conducted, which indicates that the raw material used in the study area is only suitable to produce high quality bricks with the use of advanced technologies. As the brick industry directly affects the food production a technological development in that region by using the same raw material is not advisable.

Abbreviations

AAU	-	Alpen Adria University
AC	-	Area Consumption
BIM	-	Building Information Modelling Software
BMR	-	Basal Metabolic Rate
BP	-	Brick Production
CO	-	Carbon Monoxide
DRI	-	Direct Reduced Iron
EC	-	Energy Consumption
FAO	-	Food and Agricultural Organization
GIS	-	Geographic Information System
GPS	-	Global Positioning System
GSA	-	Grain Size Analysis
INR	-	Indian Rupees
MC	-	Material Consumption
MEFA	-	Material and Energy Flow Analysis
MMR	-	Mumbai Metropolitan Region
NGO	-	Non-governmental Organization
NO_X	-	Oxides of Nitrogen
SCC	-	Specific Coal Consumption
SEC	-	Specific Energy Consumption
SMC	-	Specific Material Consumption
SO_2	-	Sulphur Dioxide
SOM	-	Soil Organic Matter
SPM	-	Suspended Particulate Matter
STA	-	Simultaneous Thermo Analysis
TISS	-	Tata Institute of Social Sciences
USGS	-	United States Geological Survey
XRD	-	X-Ray Power Diffraction

Index

1. Introduction 1

1.1 Research Stay in Mumbai 1

1.2 The Research Question 1

1.3 Introduction to the Study Area 2

1.3.1 The Western Ghats 2

1.3.2 Tansa Valley and the Study Area 2

1.4 Partnership with a local NGO 7

2. The conceptual Framework of Social Metabolism as applied to Brick Kilns 8

2.1.1 Sustainability and Society-Nature Interaction 8

2.1.2 The Concept of Social Metabolism 10

2.1.3 The socio-economic System of the Brick Industry in the Study Area 11

3. Methods and Data Collection for a local Material and Energy Flow Analysis (MEFA) 12

3.1.1 Seasonal Limitations 12

3.1.2 Localisation of the operating Kilns in the Study Area 12

3.1.3 Direct Observations in a Brick Kiln 12

3.1.4 Direct Observations in the Study Area 15

3.1.5 Estimating Material Consumption 15

3.1.6 Estimating Energy Consumption 16

3.1.7 Estimating Area Consumption in the Study Area 17

3.1.8 Estimating Area Consumption of a 20-floor Apartment Building in the MMR 17

3.1.9 Soil Mineralogy and Grain Size Analysis 18

3.2 Qualitative Interviews with Stakeholders 18

3.3 Preparation of Maps 18

4. Findings 19

4.1 The Production Process 19

4.1.1 The Kilns 19

4.1.2 Labourers 19

4.1.3 Preparation of the Raw Material 19

4.1.4 Firing of the Kiln 20

4.1.5 The Bricks 20

4.2 Green Brick Analysis, Material, Energy and Area Consumption of the Brick Industry in the Study Area 23

4.2.1 Grain Size Analysis 23

4.2.2 Soil Mineralogy and bound Elements 23

4.2.3 Material Consumption per produced Tonne of Bricks 23

4.2.4 Deviations between the 9 Kilns in Material and Energy Consumption 27

4.2.5 Material and Energy Consumption of the entire Brick Industry in the Study Area 28

4.2.6 Material and Area Consumption in the Study Area in the last 3 Seasons 30

4.2.7 Scenarios for the Consumption of agricultural Area 31

4.2.8 Brick and Soil Consumption for a 20 Floor Apartment Building in Mumbai 33

4.3 The regional, social and economic Context of the Brick Industry in Tansa Valley ... 35

4.3.1 Agriculture and Finances 35

4.3.2 Brick Making, Soil and Environment 36

4.3.3 Water and Irrigation 38

5. Discussion 39

5.1 Fuel, Emissions and Energy Efficiency in Brick Production 39

5.1.1 Biomass and Coal as Fuel for the Kilns 39

5.1.2 Emissions from Brick Kilns 40

5.1.3 Energy Efficiency of Brick Kilns 41

5.2 Consumption of Area and Soil for Brick Production 43

5.2.1 Area Consumption through urban Expansion 43

5.2.2 Use of fertile surface Soil for Brick Production 43

5.2.3 Soil Degradation and Fertilizer Use 44

5.2.4 Soil Savings through technical Improvements in Construction Materials 45

5.3 Consumption of Water for Brick Production 46

6. Conclusion 47

7. Acknowledgements 48

8. References 49

1. Introduction

1.1 Research Stay in Mumbai

Through the student exchange programme *Joint Study* and the partnership between my home institution, the Alpen Adria University (AAU) and the Tata Institute of Social Sciences (TISS), I was given the opportunity to spend over a year in Mumbai, India. During the two exchange semesters at TISS I gained insight into different topics regarding development and environment in India and was able to prepare for my thesis and fieldwork.
Environmental issues are visible throughout the city and at the beginning of my stay I felt overwhelmed by the problems an Indian megacity like Mumbai is confronted with. My biggest concern was the question what I, as a foreigner, could have to offer in order to somehow contribute to a more sustainable and more environmentally friendly development. Soon it became very clear that I had to find a local partner who works in the field and directly with the people, so I could understand the problems from a bottom up perspective. I found my partner in a local NGO named *Vanashakti*, a Sanskrit expression meaning: "power of the forest". The work of *Vanashakti* is oriented around several aspects, all connected to urban development and the present construction boom, which is visible throughout the entire Mumbai Metropolitan Region (MMR). The city is not only growing horizontally, but also vertically through a large amount of high-rise buildings, which consume enormous quantities of materials extracted mainly in the rural hinterlands of Mumbai. In one of these heavily exploited areas *Vanashakti* is involved in environmental education for school children, by conducting teaching units in local schools and organizing environmental awareness programmes. The Tansa Valley is mainly rural but belongs to the MMR and its close vicinity to the urban areas makes it especially vulnerable to overexploitation. Stone quarries break down entire mountains for minerals, while sand mining takes place in the riverbed and many farmers of the region start producing burnt clay bricks out of agricultural soil in the dry season. It is this last topic that caught my attention in a special way, seeing as in this situation the depletion of a natural resource not only impacts a natural system, but also affects the food production for humans in a devastating way. Some farmers generate an additional income in the dry season by buying soil from other farmers in desperate financial situations, and processing it into burnt clay bricks for the development of a megacity. My approach to this situation was to generate quantitative data for an impact analysis and to shed light on the social reasons behind this development.
The present study is an analysis of a misguided development that results in an overexploitation of a natural resource, which humans are directly dependent on for food production. I hope it contributes in a useful way toward a change in this unsustainable path and helps give an understanding of what is actually happening on site. I also hope that it helps *Vanashakti* to reach their sustainability goals in this fascinating region.

1.2 The Research Question

Socio-ecological impacts describe anthropogenic effects on natural systems and their feedback to society. The brick industry in Tansa Valley affects the food production by depleting soil from agricultural areas for urban construction. The socio-metabolic analysis helps quantify and understand the effects of the industry on the natural resource stock and enables an outlook into the future. The research question *Socio-ecological Impacts of Brick Kilns in the Western Ghats: A socio-metabolic analysis of small-scale brick industries in the Mumbai Metropolitan Region, Maharashtra, India* points out the described parameters and highlights the impact of the brick industry in an ecologically very sensitive region, the Western Ghats.

1.3 Introduction to the Study Area

1.3.1 The Western Ghats

In order to understand the underlying parameters of the study area, it is necessary to look at the greater geomorphological landscape first. The Western Ghats are the second largest mountain range in India and stretch along the west coast of the Indian peninsula over the six states Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat. A central defining feature is the 1600km long escarpment with an average altitude of 1.000m and a relatively steep slope westwards into a coastal plateau, known as Konkan in the north and Malabar in the south. Eastwards the Western Ghats stretch into the elevated Deccan plateau, building the central landmass of the Indian peninsula. The geologic structures of the southern part of the Western Ghats consist mainly of gneisses, granites and charnockites from the Pre-Cambrian era, while the northern part beyond the 16° latitude is shaped by 80-100 million year old flood basalts. The great escarpment most likely came into existence through the segregation of the Seychelles micro-continent from the Indian continental plate during the late Cretaceous and was further shaped through weathering processes in the millions of years to follow. The Western Ghats are also known as *Sahyadri*, the Sanskrit word for benevolent mountain, while the Hindi word *Ghat* describes stairs or a slope leading into a river or a lake. The three highest elevations are Anai Mudi (2695m) and Doda Betta (2637m) in the southern and Kalsubai (1646m) in the northern part of the mountain range. These geological features significantly influence the climate on India’s west coast by bringing abundant rainfall to the entire region, known as the Indian southwest Monsoon, from June to September. The climate from October to May is relatively dry and most of the 2000 – 6000mm of annual rainfall occurs during the months of the Monsoon (Kale 2010).

The high precipitation levels in the Western Ghats yield rivers which either flow to the east into the Deccan plateau, reaching remarkable lengths like the river Krishna with a length of over 1000km, flowing into the Bay of Bengal, or to the west into the Konkan or Malabar plateau, ending in the Arabian sea after a relatively short distance. It is these unique geological conditions that formed the Western Ghats for a long time and shaped a highly sensitive region and one of the eight biggest biodiversity hotspots in the world, inhabiting a wide range of significant flora and fauna. Among them well known and endangered species like the Lion-tailed macaque, the Bengal tiger or the Asian elephant (Myers et al. 2000; Nameer 2001; Kale 2010).

Located in the northern part of this fascinating landscape, a valley shaped by the unique characteristics of the Western Ghats and the Tansa River is gaining much attention not only as cultural and natural heritage, but also as an important supplier of resources for an urbanisation process of one of India’s booming mega cities and its metropolitan region. The close distance to Mumbai makes the Tansa Valley extremely vulnerable to overexploitation of natural resources.

1.3.2 Tansa Valley and the Study Area

As shown in figure 1 the study area is located in the Tansa Valley, which is part of the Thane district in Maharashtra, the second most populated state of India. Southwest of the study area, in a linear distance of approximately 30km, the island of Salsette where Mumbai is located begins. Mumbai, with 12,5 million people India’s most populated city, forms the MMR together with 7 other municipal corporations. This represents India’s greatest urban agglomeration with a total population of 18,4 million (Census Organization of India 2011). It is the close distance to this ever-growing gigantic urban agglomeration and the region’s natural and cultural heritage that puts it in a difficult position between India’s development goals and preservation needs.

The Tansa River, which gives the valley its name, originates near Khardi in the western hills of the Western Ghats, in a linear distance of about 70km from Maharashtra's coastline. It is one of the tributaries of the Vaitarna River 12km before it pours north of Mumbai close to Virar and into the Arabian Sea. Relatively close to its source, the Tansa River has been dammed and fills the Tansa Lake, which is one of Mumbai's main water reservoirs to supply the city's enormous demand for potable water (Brugger 2009). The annual rainfall of an average of 2300mm happens to the greatest extend during the monsoon season from June to October (Sharma 2004) and so the river lays almost completely dry in the late months of the dry season, leaving only small ponds of water that are used by the local population for various purposes. The riverbed has a number of hot springs with a reservoir temperature of more than 100°C, which are located close to the study area in the villages Ganeshpuri and Akloli. At some places the water flows into artificial ponds with a temperature of around 50°C, where people take baths to benefit from the recreational and health effects of the thermal water (Sarolkar 2005; Razdan, Agarwal, and Singh 2008). In Ganeshpuri the ponds are located in a temple that attracts not only people from the region, but also numerous tourists. The valley offers a rich cultural history that reaches back to the early and middle stone age, testified by a high number of objects found in the region (Sharma 2004).

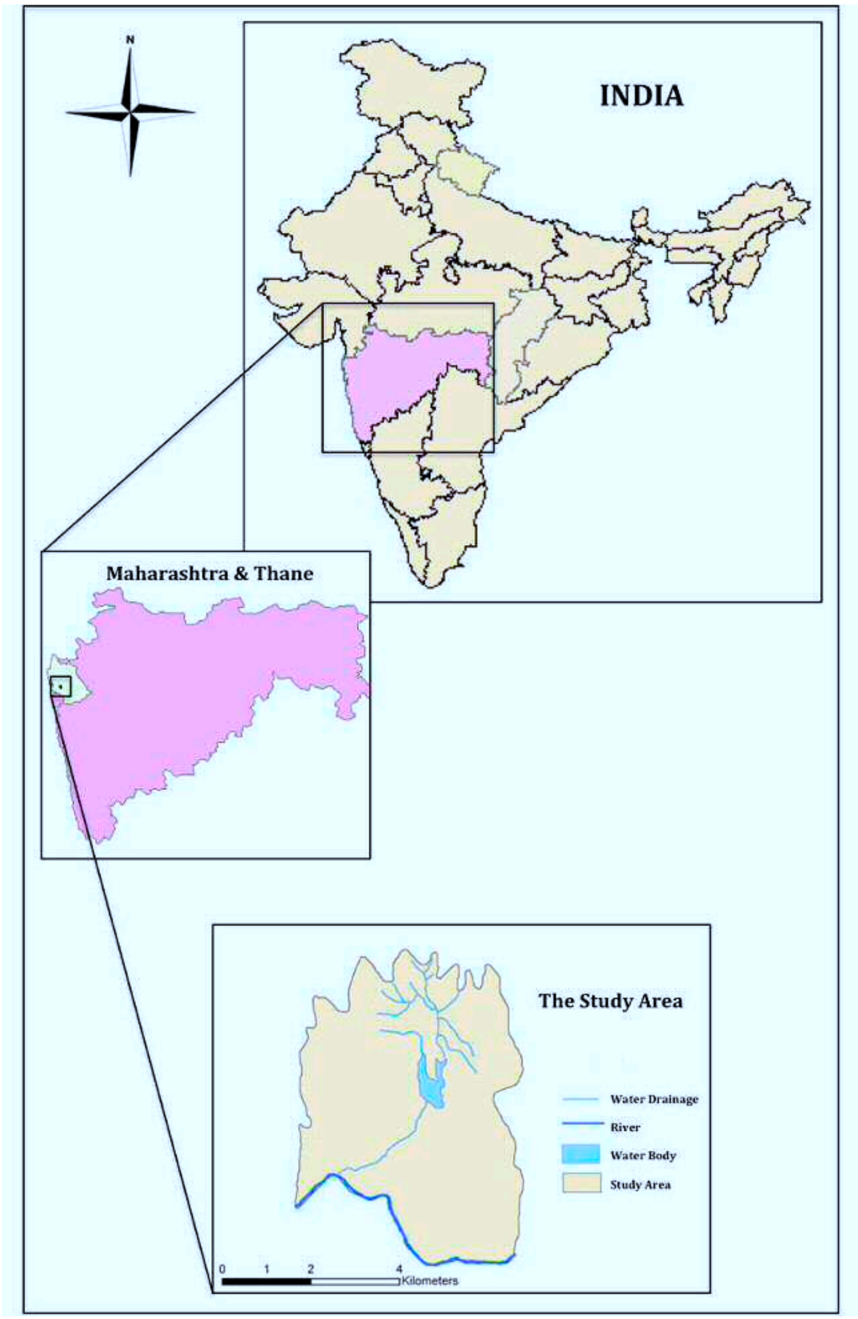
On its way to the sea, the Tansa River cuts through numerous forested hills and agriculturally shaped lowlands. The moist deciduous forests of the region are not only home to various plant and animal species, but also to nomadic tribal groups who are dependent on these forest ecosystems. The forest soils are important for storing the rainwater and filling the groundwater during the dry season, something which the villagers in the lowlands also depend on. The forests of the Tansa Valley have been exploited for at least 2500 years but in the last century the level of disturbance increased and significantly affected the water storage capacity and availability in the dry season (Veach, Lee, and Philippi 2003; Aneerudha and Sonal 2011).

1.3.2.1 Soil Types

The lowland is dominated by two soil types, which are highly fertile and therefore ideal for agriculture. Black soils, also known as *black cotton soils,* are clay rich black coloured soils formed through weathering from basaltic rocks with up to 1,5m deep cracks in dryer seasons (Spektrum der Wissenschaft 2014) and covering most areas of the entire state Maharashtra. Black soils have a relatively high clay content with 30-60%, are mildly alkaline and reach a depth of more than 60cm in the lowlands. Red soils are formed from various materials like granite, gneiss, trap and others. These soils also have relatively high clay content, are slightly acidic and reach a depth of more than 60cm in the valleys. Both soil types are highly suitable for paddy in the Kharif season, as well as other crops in both the Kharif and Rabi season[1] and are used in the brick industry as raw material for red coloured burnt clay bricks (Thaware, Kunkerkar, and Shivade 2011).

[1] Kharif-crops are planted and grown in the monsoon season and require a high amount of water while rabi-crops are planted in the dry season, require lesser water or irrigation.

Figure 1: The location of the study area on the west coast of Maharashtra, India



1.3.2.2 Agricultural Activities

From June to December the Tansa Valley appears in a lush green and is dominated by rain-fed rice cultivation, while from January to May it is dominated by dry paddy fields with black soils and deep cracks, reddish-brown basaltic rocks, dry and pallid vegetation but also dry and uncultivated land. Distinctive for the entire region in the dry season are also its brick kilns that start operating in December after rice harvest and stone quarries, extracting other highly important minerals for the urbanisation process of the MMR.

The soil and climatic conditions in the valley are ideal for rice, but as the agriculture in the study area is only rain-fed, paddy fields are fallow in the dry season and only a few fields are planted with rabi-crops. Images of the study area are shown in figure 2.

Figure 2: Images of the study area: a) View at the study area north of Tansa River at the right bottom of Mandagni Mountain b) The Tansa River in April with ponds of remaining water c) Chambale; one of the villages in the study area d) Rabi crops close to Chambale and the Tansa River e) The study area and Mandagni Mountain presents itself in a lush green during the rainy season f) Agricultural land in the study area at the beginning of Kharif season

1.3.2.3 Physiography and Land Cover

The study area is defined through a watershed that is shaped in the west and east by mountain ridges, which connect at the northern side of the area and enable the entire water runoff into the Lohape Talao Lake in the centre of the watershed and further into the Tansa River that marks its southern border. The area is a rural agricultural region, but very much shaped through the fast urbanisation of the MMR, mainly through resource extraction but also by emigration of the young population into the urban centres. The mountain ridge is dominated by forests and contains a few stone quarries on the eastern side while a higher elevation named Mandagni Mountain is located on the western side of the watershed. It is covered with forest and has some reddish rocky plateaus. It also has spiritual value for the population of the entire region and no mineral extraction was observed in the closer vicinity to the mountain. Small springs and streams originate in the hills and lead into the watershed, some of which dry up entirely in the dry season while others yield water throughout the year. The Tansa River stops flowing in the late dry season, but the riverbed south of the study area does not dry out entirely and contains greater pools of water throughout January to June. The study area contains the four villages Kelthan, Chambale, Dakivali and Lohape with a total population of 5204 (Census Organization of India 2011), as well as one larger and a few smaller settlements. In the left map of figure 3, the four villages and one larger settlement are marked with green triangles, while the nine identified brick kilns are marked with black dots.
The land use map in the right part of figure 3 shows six specified land characteristics marked in different colours. The total watershed covers 29,51km^2, of which *Natural Vegetation* (green colour) covers 8,79km^2 and is defined as all vegetation of the area that is not agricultural area, which mainly consists of light forests and bush vegetation. *Buildup Area and Open Land* (brown colour) covers 8,25km^2 and consists either of rocky plateaus, as in the case of the top of Mandagni Mountain at the north-western edge of the watershed, or of villages and other human created structures like brick kilns, but also freshly depleted areas for soil extraction. It is important to mention at this point, that brick kilns can cover relatively large areas because the freshly moulded green bricks are sun-dried and require much space. *Agricultural Land* (yellow colour) covers 7,63km^2 and defines all areas that are actively used for agriculture, which means that these areas are used as agricultural land at least for the Kharif season, while *Waste Land* (light grey colour) covers 2,55km^2 and marks all areas that are not used for agriculture and have no distinctive vegetation cover. *Stone Quarries* (dark grey colour) cover 1,42km^2 and indicate that resource extraction is happening on a great scale in the study area, not only by soil extraction for brick production, but also for other minerals. The smallest share of 1,42km^2 is covered by *Water Bodies* (blue colour) and is characterized by the Tansa River to the south, Lohape Talao Lake in the centre, and smaller streams yielding the lake. The fact that brick kilns are located so close to water bodies and agricultural areas already indicates what the two most important resources for brick production are in terms of quantity.

Figure 3: a) Villages, brick kilns and water bodies in the study area b) Land use map of the study area

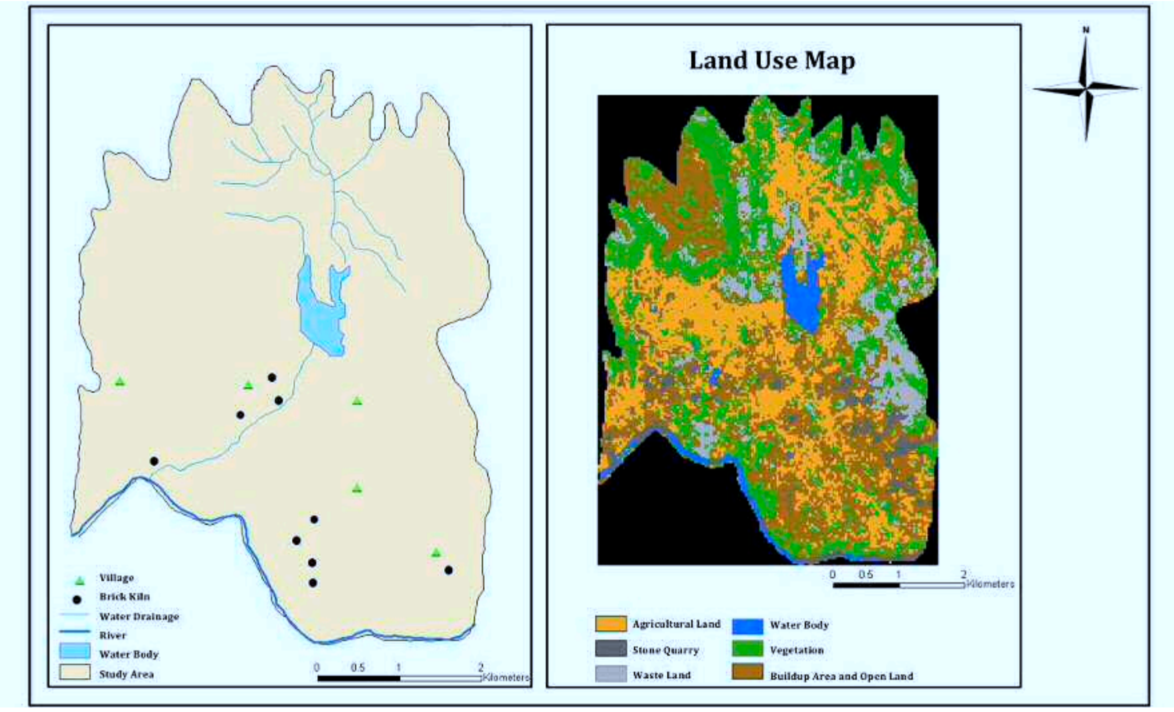


Table 1: Area size of different land use categories

Land Use	km2	ha
Vegetation	8,79	879,00
Builtup Area and Open Land	8,25	824,65
Agriculture	7,63	762,92
Waste Land	2,55	255,26
Stone Quarry	1,42	142,14
Water Body	0,87	87,37
Total	**29,51**	**2.951,33**

1.4 Partnership with a local NGO

A research project in a foreign country can be a fascinating but also challenging experience at the same time. Without local partners this experience can become far too challenging because not only the knowledge of the relevance of regional environmental problems, but also the access to these regions, is often limited. The partnership with a Mumbai based NGO helped to assess the relevance of conducting a study about brick making in the Tansa Valley, not only academically, but also practically. *Vanashakti* is concerned with environmental issues in the entire MMR and also works in the Tansa Valley. From the beginning the aim of this study was to be as close as possible to the basic realities and to contribute to the overall improvement of the situation in the study area. The partnership with a local NGO has proven to be very beneficial for both sides.

The local language in the study area is Marathi and so it was necessary to have a translator in the field. Experience however revealed, that the local farmers in Tansa Valley are not very open with their information on brick making to unknown people. In this regard, the network of *Vanashakti* through their environmental awareness programmes with schoolchildren was of great importance. Most of the farmers have children that are taught in school by employees of *Vanashakti,* who were then introduced to the parents. Once this relationship was established, farmers' houses were always open and it was not only possible to interview them but also to spend sufficient time on the sites of brick kilns, talk to the labourers, take measurements and even use their tools for moulding green bricks for study purposes. Trust is an important thing if questions about peoples businesses are asked, and the overall impression was that brick makers and farmers were finally very open with their information.

As mentioned, a partnership with a local NGO can have enormous advantages for work in the field. Establishing this network without local partners would require a long time in the field, which can be circumvented but at the cost of dependence. Establishing a partnership like the one described here is a promising strategy, but it must be kept in mind that in this situation work in the field is almost impossible without these local partners. As the major part of the fieldwork for this study could only be realised during the months December to May, the available time was limited. As employees from NGOs mostly also have other duties than assisting researchers in the field, it demands good planning. But if unforeseen things happen, even the best planning proves to be useless. This became a problem when the first rains hit the region and the brick kilns were about to shut down for the season. Data still had to be collected and at the same time the NGO needed all their capacity somewhere else. This situation of absolute dependence on other people can also be quite challenging, especially when there is a shortage of available time to finish the work.

In addition to this, it is also worth mentioning that having a local partner in the field who is capable of understanding what the whole study is about, and why certain data needs to be collected, is a big advantage because sometimes the right questions need to be asked at the right time without any translations. Therefore a local partner, who speaks the language, knows people from the area and is accepted by them and is also capable of understanding the background of the study, is essential in the field.

At the end all work could be finished and all the data collected. It is a question of negotiation, patience and goodwill on both sides to accomplish the goals set. Dependence can be challenging, but the inaccessibility of information in the field can be much more challenging. Therefore looking for a local partner and working together with *Vanashakti* was the right thing to do and this study could have never been accomplished in such a satisfying way without their assistance.

2. The conceptual Framework of Social Metabolism as applied to Brick Kilns

The brick industry in Tansa Valley can be characterised as a *socio-ecological system* that is shaped through exchange of material and energy between natural systems and society. The methodology of the present study is based on a systemic conception of society-nature interactions, but before the methodological approach can be fully understood, it is important to clarify the meaning of sustainability and society-nature interaction and its connection to the brick industry in Tansa Valley.

2.1.1 Sustainability and Society-Nature Interaction

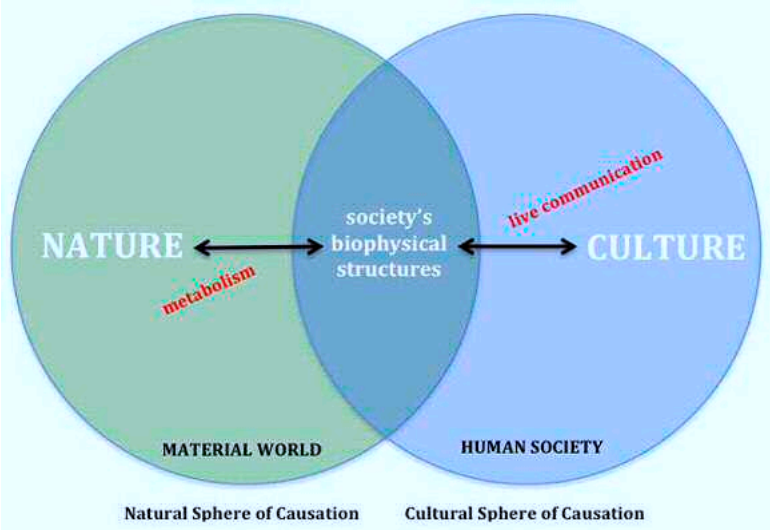
Sustainability is an anthropocentric concept that aims to establish a certain balance in human-nature interactions and can be defined as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Ecosystems change over time and sustainable development does not necessarily mean that these ecosystems must be kept in an equilibrium state, but it indicates that the interaction of societies with natural systems should be managed in a way that don't cause any harmful feedback to the wellbeing of humans (Haberl et al. 2004). Wellbeing of humans is a broad definition and not every aspect can be quantified in an easy way, but there is no doubt that food is a basic need for all life and therefore essential for human wellbeing. The brick industry in Tansa Valley directly impacts the food production system and could threaten the livelihood of present and future generations by degrading agricultural soil and consequently also eroding the economic basis of farmers throughout the region. Fertile soil is a renewable resource formed by long term weathering processes of different types of rocks under accumulation of organic substances. The extraction of a renewable resource can only be classified as sustainable, if the extraction rate does not exceed the renewal rate. Anthropogenic soil management can influence the content of organic substances in the soil, but if the mineral content is not replaced at a rate close to the depletion rate, the practice of soil extraction for brick making must be classified as unsustainable.

Sustainability or unsustainability describes the character of society-nature interactions and is therefore an "attribute of a *socio-ecological system"* that "emerges through the interaction of a society with its natural environment" (Haberl et al. 2004). The systems approach helps to better understand the causations of certain patterns of society-nature interactions, and is at the same time the basis for the concept of social metabolism. The *socio-ecological system* as shown in figure 4 consists of a natural and a cultural sphere of causation and the biophysical structures of society in their overlapping area[2]. The natural (biophysical) sphere of causation represents the material world, which is shaped by society interacting with nature through social metabolism. This interaction is determined by the society's reproduction through live communication represented by the cultural (symbolic) sphere of causation (Fischer-Kowalski and Erb 2006).

To understand why society-nature interactions are shaped in the way they are, it is beneficial to analyse both spheres of causation. As the cultural sphere influences the physical exchange between society and nature, changes in this sphere also cause changes in society's interaction with natural systems and vice versa. In the case of the brick industry in Tansa Valley, it is necessary to look at the biophysical aspects of the exchange between the industry and nature, but also at the cultural sphere to identify the reasons and the potential for change. Before the methodology is outlined in detail it needs to be clarified what exactly the exchange of materials and energy, referred to as social metabolism, is and how it can help to analyse and identify sustainable or unsustainable development in society-nature interactions.

[2] Society describes a social form of organization with the aim to reproduce itself culturally and biophysically, while nature encompasses all material elements (also agricultural ecosystems) except human beings, their livestock and artefacts, which represent the biophysical compartments of society in the overlapping area of the cultural and natural sphere of causation (Fischer-Kowalski and Erb 2006).

Figure 4: The socio-ecological system with the natural and cultural sphere of causation and the biophysical parts of the society in the intersection



2.1.2 The Concept of Social Metabolism

Social metabolism is a concept in analogy to the biological concept of metabolism, which describes the chemical transformations within cells of living organisms to sustain their life supporting systems. The cultural evolution of human societies led to an extension of the metabolism where not only basic life-supporting needs are fulfilled, but also other needs, e.g. clothing, housing or cooked food. The concept of social metabolism describes the exchange of materials and energy between human societies and their natural environment and is therefore a useful concept to quantify the human impact on natural systems. Depending on the nature of resources societies use, their social metabolism can rely only on renewable resources or on both, renewable and non-renewable resources, like fossil energy carriers[3]. If a society only uses renewable resources, their social metabolism is described as a basic metabolism, which can lead to sustainability problems mainly on the input side if resources are overused. If a society also uses non-renewable resources, their social metabolism is described as an extended metabolism which can lead to sustainability problems on the input, but also on the output side if natural systems are not capable of absorbing the final products of the society's metabolism (Fischer-Kowalski 1997). The concept of social metabolism is mainly applied at the national level by defining an entire country as a socio-economic system, but it can also describe subsystems like regions, cities or villages or even industries like the small-scale brick enterprises analysed in the present study (Haberl et al. 2004; Krausmann et al. 2004; Singh et al. 2010).

The MEFA (Material and Energy Flow Analysis) framework is a tool, which helps analyse the social metabolism of socio-economic systems. The aim is to identify and measure all biophysical stocks and material and energy flows of one year between a defined socio-economic system and nature, either through direct measurements or on the basis of surveys. For a precise estimation of all involved material and energy flows it is essential to exactly define the system boundaries of the observed units (Singh et al. 2010).

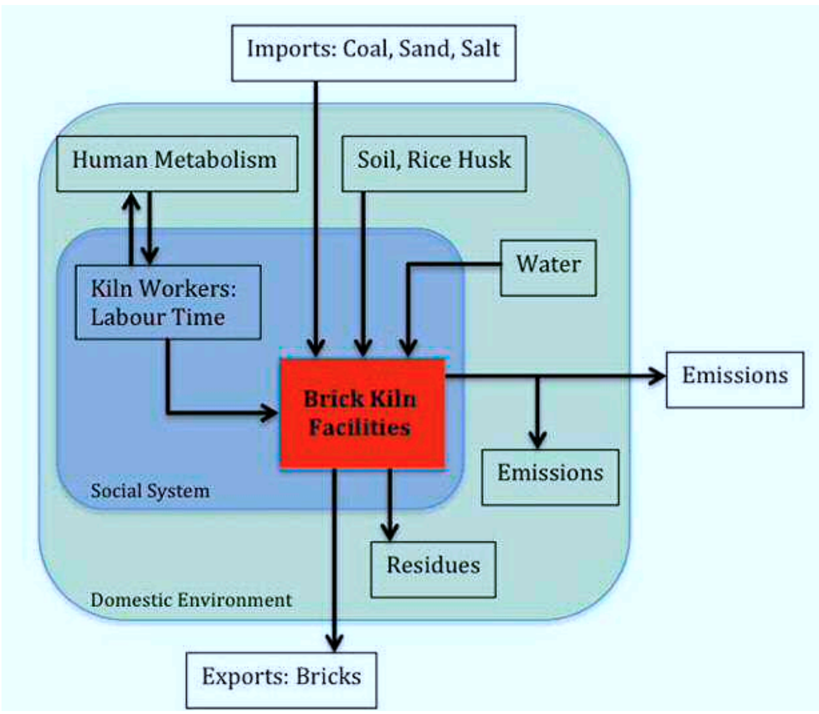
[3] Fossil energy carriers are considered as non-renewable resources because their renewable rate exceeds the anthropogenic time horizon by far. This is also true for many other resources extracted at a rate far beyond their renewal rate. Therefore renewable and non-renewable is a flexible definition depending on the time horizon in focus.

2.1.3 The socio-economic System of the Brick Industry in the Study Area

The brick industry in the study area is a regional economic sector, characterised by its social metabolism with natural systems through resource extraction for brick production and the purpose of monetary output for all people involved in the production process. Stakeholders in this sector are kiln owners, farmers who sell soil from their fields, but also labourers working in the kilns. The monetary output is created through the extraction of fertile agricultural soil and its processing into burnt clay bricks further used to build up urban stocks. The result is a net flow of material resources from the natural into the urban system, using additional materials and energy to accomplish this flow. The brick industry therefore functions as an interface between two different systems by transforming fertile soil into a product used for urban construction.

The socio-economic system of the regional brick industry in the study area is defined through its stocks and flows and is outlined in figure 5. The stocks are all labourers and machinery, as well as the area used for brick production, while flows are physical or energetic in nature. The system maintains itself through the import of coal, sand[4], salt and the domestic extraction of soil, rice husk and water. The required energy for the processing of fertile soil into burnt clay bricks is supplied by coal, rice husk, diesel, petrol, labour but also soil organic matter (SOM) bound in the raw material used for brick production. The only valuable export product are bricks, while the residues and emissions affect mainly the domestic but also the external environment. The labourers stay in an exchange with the domestic environment through their human metabolism.

Figure 5: The socio-ecological system of the brick industry in Tansa Valley



[4] Sand could also be partially extracted from the Tansa riverbed but its origins were not examined in the present study.

3. Methods and Data Collection for a local Material and Energy Flow Analysis (MEFA)

3.1.1 Seasonal Limitations

Every year the brick industry starts operating again after rice harvest between November and December. The kiln workers usually start their work in the beginning of November by clearing the fields for brick production and excavating the pits for preparation of the raw material. The first brick kilns are fired up by December and the first bricks of the season are available two weeks later. In some years bricks from the last season's production are still present and can be sold before the actual production starts. The season lasts until the first monsoon rains hit the region by the beginning of June, disturbing the drying process and making the production impossible. Only within this six-month timeframe it is possible to observe the whole process of brickmaking in Tansa Valley. For this study a total of 21 days were spent in the project region from April to July 2014. In this season the monsoon started much later than expected, but early rains in the beginning of May prompted manufacturers to shut down the production by the middle of the same month. Data collection at the brick kilns was accomplished between April and mid-May 2014, while surveys continued until the end of July 2014.

3.1.2 Localisation of the operating Kilns in the Study Area

Google Earth was used to identify and locate the brick kilns operating in the last ten years in the watershed. The nine identified kilns were marked on a map and their location verified using a GPS device in the field. All nine brick kilns were observed and their managers identified, while one brick kiln was chosen for the detailed analysis of the production process and direct measurements.

3.1.3 Direct Observations in a Brick Kiln

During five days at the beginning of May, the production in the one chosen brick kiln was on a normal level and a precise analysis of the entire process of brick production and identification of all material and energy flows was possible.

Soil[5] is the basic material for bricks, while the production also consumes significant amounts of water, sand, rice husk, salt, coal, diesel and petrol. The required energy is supplied by fossil fuels, rice husk, SOM and by human labour[6]. The estimations of soil and water consumption were achieved on the basis of measurements taken directly at the kiln, while the consumption of other raw materials such as sand, rice husk, salt and coal were inquired from

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[5] It had been observed that three different categories of soils are used for brick production. The major share is black and red soil taken from agricultural areas and uncultivated land, while sometimes soil from the forested hills is added. For this study soil is treated only as agricultural soil, which is acceptable considering the fact that most of the soil comes from paddy fields or areas suitable for agriculture. The dominant soil type used for brick production is black soil, while uncertain amounts of red soil are often mixed to the raw mass.

[6] Some brick manufacturers also use dried manure as energy carrier and mix it to the coal and the rice husk as fuel to save costs. Also iron filings are sometimes used instead of sand and fly ash (airborne residues of combustion processes in coal fired power plants) is sometimes added to the raw material for bricks to reduce the amount of soil. For these materials, no quantities were given but mentioned that their use is more exceptional than frequent. Also labourers collect wood from the surrounding forests for housing structures and cooking. Measurements revealed that one family, usually two workers and their children, consume about 23kg of dry wood per week. The quantities of these materials were not included in the calculations.

the managers through surveys. Diesel and petrol consumption were calculated by the fuel consumption of the tractor used for the transport of soil and rice husk, and the pump delivering water from the river or ponds to the kilns.
To estimate the volume of soil that is consumed for the production of a specific amount of bricks, three samples of 0,027m^3 (30x60x15cm) each were taken from three different locations on paddy fields within one kilometre distance from the brick kiln. The soil samples were measured in volume and weight and brought to the brick kiln, where they were further processed into green bricks, to calculate the amount of bricks that could be formed out of that specific volume. Images of the soil samples and the processing into the mouldable raw material for green bricks are given in figure 6 (a-d). To estimate the water consumption in the production process, three pits used for preparation of the raw material for bricks were measured, their volume calculated[7] and the amount of green bricks moulded out of these three pits was counted. The process of brick making will be described at a later point in this study. Attention was also paid to the size and weight of the bricks produced in the study area and bricks were weighed and measured in three different states: wet, sun-dried and burned. Two different sizes of bricks produced in the valley were identified and the differences in weight and production numbers included into the calculations.

[7] For the preparation of the raw material for brick production a certain amount of pits are excavated at the beginning of the season directly at the site of the brick kilns. The number of pits depends on the size of the area for brick production, on the amount of labourers and achieved production numbers. These pits are distributed all over the area and closed with soil and sometimes residues from the kilns after the season. Once the field is under cultivation again, there are no traces left. The volumes of the pits were calculated with the volume formula for a trapezoidal prism: $V = h \div 3\left(A_1 + \sqrt{A_1 \times A_2} + A_2\right)$.

Figure 6: a+b) The extraction of 3 soil samples with a specific volume from 3 paddy fields close to the brick kiln c) Adding water to the soil samples and soak it for several hours to prepare a mouldable mass for green brick production d) Preparation of the raw mass for green bricks e) Paddy field with depleted upper layer for brick production f) Paddy fields with multiple depleted layers for brick production

3.1.4 Direct Observations in the Study Area

Many journeys had to be undertaken throughout the entire watershed, as well as into the surrounding region in order to gain a comprehensive understanding of the characteristics of human activities in the Tansa Valley.

Direct measurements were taken at the sites of the kilns by counting the number of pits and measuring the size of bricks, and also on fields which were recently depleted for brick production. To estimate the area affected by soil extraction, the depth of the depletion was measured at three locations within the study area. The two photographs (e-f) in figure 6 show two agricultural areas recently used for soil extraction. Further three soil samples of moulded green bricks were taken from different kilns and later analysed in a geological laboratory in Vienna.

3.1.5 Estimating Material Consumption

For all commodities and materials that could not be measured directly at the brick kiln, surveys for the brick kiln managers were outlined. Interviews with all nine brick manufacturers in the study area were conducted to estimate the amount of sand, rice husk, coal, salt and potentially other materials used for the production of bricks. The questions were directed towards material use and sources of these materials, but also concerned labour, production numbers, losses and transport distances of the raw material. The interviews have not been recorded and were translated directly on site. The number of produced bricks within the watershed was crucial to account for, as it was the basis for consumption numbers of all other commodities and energy. Brick manufacturers in the study area don't keep any record of production numbers and recall the annual production out of their minds. Uncertainties in the production numbers and the numbers of labourers, given by the brick manufacturers, but also the size of the brick kilns lead to the assumption that the numbers given might not be very precise. Therefore an additional method was developed to be able to rely on more than just the numbers memorized by the brick kiln managers.

The field of duties in a brick kiln is strictly organized and the moulding of green bricks limited to a certain amount of workers, the so-called *pit workers*. A pair of *pit workers* is paid to produce 100000 bricks plus 10% for the losses per season, and each pair works on two pits. The final production numbers used for this study were estimated by the averaged sum of three different production numbers: I.) The numbers given by the kiln managers; II.) The production numbers that the given amount of *pit workers* would be able to produce in one season; III.) An estimation of production numbers drawn from the amount of pits counted on the site of the kilns[8]. The approach of calculating an average over the three estimation methods seemed the most promising as for some kilns the divergence of the three estimates was rather large. The average number seemed to give a best estimate for the actual production. Data on memorized production and labourers for the last three seasons could be collected, but the number of pits was only available for the current season 2013/14. The production numbers for the seasons 2011/12 and 2012/13 had to therefore be calculated from the average of given production numbers and number of pit workers only.

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[8] For the better understanding an example is outlined: *A brick kiln with 20 pits could produce 1 million bricks per season. The brick kiln manager said that he employed 16 pit workers in the same season which would result in 800000 produced bricks (As mentioned in the text, a pair of pit workers is paid to produce 100000 bricks per season). The brick kiln manager then also said that he produced 700000 bricks in that season. As the three numbers don't match the average sum of 833000 bricks would be chosen to account for the seasonal production of the kiln.*

Kiln managers were also questioned about the soil depletion process and if they use their own land and soil for the brick production. They gave numbers of the depleted depth, which matched to the measurements taken on three sites in the study area. They also gave numbers on the distance the soil is transported, the kind of vehicle used for the transport and its loading capacity.
Other questions concerned the total number of labourers and the labour organization in the brick production process. Another issue was how long the seasons had lasted in the past 3 years, and how many sizes of bricks they produce. If other sizes were produced, the production numbers were considered in the calculations.

3.1.6 Estimating Energy Consumption

To estimate the overall energy consumption of a brick kiln, various key variables were identified and calculated.
Coal: As most of the brick manufacturers use a mix of Indian and Australian coal, two different numbers were used for the energy content of coal. The energy content of one kg coal was taken from datasets from the *USGS World Coal Quality Inventory*. For Australian coal only one number was available and indicated the relatively low calorific value of 14,72MJ/kg, while for Indian coal all samples analysed were from the same region in Madhya Pradesh and showed 83 different values of which the average of 22,24MJ/kg was chosen (USGS 2014). The specific regions of the coal's origins were not given for the Australian coal and kiln managers indicated central India for the coal of Indian origin. Madhya Pradesh is located in central India and contains one of India´s largest coal reserves (Indian Ministry of Coal 2014).
Rice husk: In Tansa Valley brick manufacturers use a significant amount of rice husk as external and internal fuel. There is sufficient information in the literature about the energy content of rice husk due to its abundance and wide usage for electricity generation in biomass power plants. The analysis of different sources of literature resulted in an energy content of 15MJ/kg rice husk (Mansaray and Ghaly 1998; Shen et al. 2012).
SOM: The soil organic matter was measured in a laboratory by analysing three samples of green bricks taken from three different brick kilns in the project region. The organic compounds of the green brick samples were measured by the simultaneous thermo analysis (STA) by calculating the weight loss at specific temperature levels between 0 and 1000°C. The average value of mass percent of the three green brick samples was calculated and applied to the total soil use for brick production. As SOM and rice husk are both present in the analysed green brick samples and to simplify the calculations, the same calorific value of 15MJ/kg was chosen and then multiplied with the weight of the organic compounds present in the soil. To avoid a double count of rice husk, the energy share of rice husk used as internal fuel, was then subtracted from the total value of SOM calculated by STA.
Diesel: The main transport of soil and rice husk is mostly undertaken by *Mahindra* tractors that have a loading capacity[9] of 2,83m^3, equalling either to 3,2t of dry soil or to 353,75kg of rice husk[10]. Regarding the producers information given on the website, the most frequently sold tractor in India is the *Mahindra Bhoomiputra MKM* that is available in 5 models ranging from 25HP to 45HP (Mahindra & Mahindra Ltd. 2014). For this study the testing paper from the Ministry of Agriculture in India for the *Mahindra 265 DI MKM Super Power* with 32HP was chosen (Government of India 2013). The PTO performance data of the chosen model

[9] The kiln managers specified a capacity of one brass per load, which corresponds to a volume of 2,83m^3.

[10] Bulk density for soil was estimated through the 3 soil samples taken in the study area, resulting in a value of 1130kg/m^3, while the bulk density for rice husk was extracted from the literature and ranges from 96-160kg/m^3 (Kumar 2012). For this study a bulk density of 125kg/m^3 was chosen for rice husk.

specifies a performance of 23,8kW with a fuel consumption of 237g diesel per kWh, which results in a fuel consumption of 282g/km and an energy consumption of 12,8MJ/km[11]. The total values of energy consumed for transport were then calculated on the basis of transport distances and the volume of soil/rice husk per load, multiplied with a factor of 1,75 for the empty trip back from the kiln to the area of soil extraction.

Human labour: There are slight variations in working schedules of different kilns. The total working hours of all labourers per season per kiln were calculated and appropriate rates for energy consumption were drawn from the literature. The available information on the energy expenditure of humans during heavy work is very divers and depends on a wide range of factors. Most adequate calculations for human energy requirements during heavy work were taken from Ramanathan and Nag (1982) who summarized energy requirements of human labour in India for agriculture between 3,3 kcal/min and 8 kcal/min or 0,83MJ/h to 2,02MJ/h (Ramanathan and Nag 1982). Smil referred to FAO calculations based on the basal metabolic rate (BMR) of adults with 55kg between 20 and 39 years and an energy requirement of 0,5 MJ/h during heavy work and adults with 65kg in the same age group with an energy requirement of 0,7 MJ/h of heavy work (Smil 2008). Lichtfouse describes calculations ranging from 0,6 MJ/h to 2,3MJ/h if the embodied energy in the food is not accounted for (Lichtfouse 2011). The labourers in the kilns are mixed groups of men and women, among them labourers under 20 years but also labourers over 35 years of age. For this study, an energy requirement of 0,6 MJ per working hour was chosen, which is probably lower than the actual additional energy requirement of Indian brick kiln labourers during heavy work.

Petrol: For the calculations in this study the widely distributed petrol powered water pump *Honda WB20XT* was chosen and its performance analysed from the available data in the model's description (Honda Motor Europe Ltd. 2014). To pump 36t water in one hour it consumes 0,75kg of petrol with a calorific value of 45,8 MJ/kg (ACEA 2013).

3.1.7 Estimating Area Consumption in the Study Area

Brick kilns operating in the study area vary in size and output, from small operating units with 20 kiln workers and an annual output rate of 1,3kt up to large units with 265 kiln workers and an annual output of 11,5kt of bricks. Socio-Metabolic profiles of the entire brick industry in the study area were outlined and its annual area consumption calculated. Simplified scenarios were outlined to understand the effects of the brick industry on agricultural areas and estimate the available time before the entire area is affected by soil extraction.

3.1.8 Estimating Area Consumption of a 20-floor Apartment Building in the MMR

To estimate the agricultural area consumed by a typical 20-floor apartment building in the MMR, a house under construction was photographed in Vikhroli, Mumbai and the potential shape of one flat estimated from pictures. A detailed floor plan of a flat with 82m^2 was outlined and the consumed bricks calculated by the use of building information modelling software (BIM). To estimate the total brick consumption of the apartment building it was assumed that each of the 20 floors contains 6 flats. The three ground floors were calculated with 80% of the brick consumption of three floors with flats. The calculations were only done for bricks and concrete, while all other materials were not considered. To estimate the brick consumption of one m^2 brick wall, which was the basis for the calculations of brick and

[11] The energy consumption of a tractor per km was calculated with the formula: $\frac{P\times C}{60}\times t/km\times MJ/g$; while P is the performance, C the consumption of the chosen tractor model, t/km is the time the tractor needs for one km (3min) and MJ/g refers to the energy content of 45,5MJ/kg of diesel (ACEA 2013). The material consumption for diesel was then also taken from this calculation.

concrete consumption, pictures were taken on different sites in the MMR and the relation of brick and concrete fugues measured.

3.1.9 Soil Mineralogy and Grain Size Analysis

Three green bricks were collected from three different brick kilns in the project region and samples taken for an analysis. The three samples were tested on biomass content, water content, grain size and overall mineralogy in a laboratory in Vienna.

3.1.9.1 Grain Size Analysis (GSA)

Regarding grain size analysis, one sample with 100g was separated and diluted with H_2O_2 for several days to separate organic matter and all loose connections between the minerals. Grain size distribution was measured by using 6,3mm, 2mm, 0,63mm, 0,2mm, 63µm and 20µm sieves. The sedigraph particle analyser (SPA) was then used to measure the grain size distribution of the particles <20µm with fractions of >6,3µm, >2µm, >0,6µm and >0,2µm. A model of the total grain size distribution was outlined for the three samples and a combined graph generated.

3.1.9.2 Soil Mineralogy and bound Elements

Soil mineralogy was measured by using the X-ray power diffraction (XRD) on all fractions and additionally only on the silt and clay fraction of the green brick samples. Graphs were generated to confirm the presence of minerals important for brick production. The total share of bound water, organic matter and Calcium carbonates was measured by using STA.

3.2 Qualitative Interviews with Stakeholders

To understand the background of the situation of farmers in Tansa Valley it was necessary to also conduct qualitative and more comprehensive interviews. Seven farmers from the study area were interviewed on topics regarding agriculture, finances, brick production, soil, environment, water and irrigation. Among the interviewed individuals were two farmers who sold their soil to brick manufacturers, three farmers who refuse to sell their soil, one farmer who produces bricks and one agricultural officer from one of the villages. The interviews were held in Marathi, the local language of the region, and recorded on audio files. Later the interviews that lasted between 30 and 90 minutes were transcribed in Marathi and translated into English. The interviews provide important information of the experienced situation of the farmers on site.

3.3 Preparation of Maps

The maps used for the description of the study area originate from a *LandSat* image with a resolution of 28m, and 15 PAN images taken in the month of January 2014 were downloaded from the USGS website (http://www.usgs.gov/). The GPS coordinates collected in the field helped identify the exact locations of the nine brick kilns. The image was processed in the GIS platform and three maps were outlined to show the location of the study area within India, the distribution of villages, brick kilns and water bodies and patterns of land use within the watershed. ArcGIS 10 and ERDAS 11 software were used to identify and digitalize land use and land cover features as well as drainages present in the study area, which were then marked with six different colours and translated into the approximate percentage of the areal cover. From the overall area covered by the watershed the share of the six different land use characteristics was calculated.

4. Findings

4.1 The Production Process

4.1.1 The Kilns

The brick kilns in the study area are intermitted kilns. These types of kilns don't have any permanent structures and are built entirely out of green bricks with a layer of burnt bricks as basis and sheathing. Intermitted kilns are also called batch kilns because bricks are piled up along with the fuel to a batch of 100000 or 200000 bricks, which are ignited once until the whole fuel is burnt and the kiln has cooled down again. The advantage of these kiln types is that compared to other technologies they require a relatively low investment at the beginning and the area they stand on can be used for agriculture again in the wet season. The disadvantages however are high energy intensity, high emission levels, no chimneys and no controlled firing process, which means the losses through overheating, melting or too low temperatures are also relatively high (Heierli and Maithel 2008).
The sites for brick production in the study area can be used for agriculture again in the rainy season, and if there are no bricks left from the dry season it is hard to see any traces of the brick production. This is crucial for the brick manufacturers because the brick business in the Tansa Valley is mainly seen as additional income to farming and not as an alternative to it. All interviewed managers buy soil from other farmers and do not, or only in exceptional situations, use their own soil for brick manufacturing.

4.1.2 Labourers

The labourers are mainly people, women and men, from tribal communities from the greater region. They migrate to the valley to work in brick kilns from November to May and then return to their villages. Labourers mostly come with their children and have often spent great parts of their own childhood in brick kilns. The families live in small houses made of wood and straw on the same land where the kiln is operating. There is always a specific amount of *pit workers* who are working in couples on two pits to produce 100000 bricks plus 10% per season. The *pit workers* receive a fixed payment per produced bricks, partly every week and partly at the end of the season.

4.1.3 Preparation of the Raw Material

The raw material for bricks is prepared in pits with an average volume of 2,3m^3. Every brick kiln has a certain amount of pits, which are excavated at the beginning and closed with soil and unburned residues from the brick kilns at the end of the season. Through this method, the area can be used for both brick making in the dry season, and agriculture in the wet season. In the project region brick kilns have between 8 and 60 pits depending on the size of the area, the annual production output and amount of labourers. The entire process of forming raw clay bricks is shown in figure 7 and lasts over more than one working day. Two pit workers always work on two pits at the same time and start filling the first pit with water and dry soil in the late afternoon of the first day. The soil is soaked overnight and processed by the pit workers with their bare feet and hands to create a smooth and mouldable mass. After the mass is thoroughly mixed and larger stones removed, rice husk is mixed into the soil to serve as internal fuel[12]. The raw mass is positioned next to the pit in the early afternoon of day two, where it rests for about 12-16 hours. To keep the moisture, especially in the outer layers of the raw material, rice husk is distributed equally on the mud. The pit workers start moulding the

[12] Internal fuel is processed into the raw mass and helps to burn the brick entirely during ignition and makes it porous, which gives the brick a better isolation performance.

green bricks on the third day before sunrise by pressing the raw material into a metal mould, forming 2 bricks at a time. Sand is added to reduce the adhesive consistency of the wet raw material, preventing it sticking to the hands of the workers, as well as the mould while moulding the bricks. When the work is finished between 800 and 1100 bricks are formed out of one pit and left in the sun and wind for drying. After a few days in the sun the green bricks are ready for the firing process.

4.1.4 Firing of the Kiln

While *pit workers* only work on the preparation of the raw material and the moulding of green bricks, other workers carry the sun-dried bricks to another spot and pile them up to form a kiln. As shown in figure 8, green bricks are arranged along with coal, rice husk and other fuel in a way that enables air to circulate. To keep the heat in the kiln, the outer layer is formed by fired bricks and in some cases sealed with mud. Also in the outer layer openings ensure that the fire, which lasts for two weeks, is supplied with enough air. After cooling down the bricks are ready to be picked up by their buyers. If the production was too high or the market glutted, it can happen that kilns stay standing for longer than one season and some kilns are entirely overgrown with vegetation, reminding the observer more of ancient structures than of contemporary brick kilns. After all bricks are removed the residues form a rather unsettling image, leaving behind an area which has little in common with agriculture. But once all residues are removed from sight and the first rainfalls soften the ground, no trace of the kilns is left behind.

4.1.5 The Bricks

Bricks are produced in two sizes in Tansa Valley. The majority are 21,5cm x 10,0cm x 7,5cm in size with a weight of 2,125kg, while some brick manufacturers produce double sized bricks that are 21,5cm x 14,5cm x 9,0cm in size with a weight of 4,3kg. The size of the bricks produced depends on the requirements of the customer. The demand for large sized bricks is generally much lower.

Figure 7: a) Unloading of soil from paddy fields into pits for preparation of raw material for brick production b) After 16 hours soaking with water in the pits the raw mass gets distributed next to the pits to let more water vaporize c) Moulding of bricks by hand with metal moulds d) Distribution of green bricks for the drying process in the wind and sun e) Bricks are carried to the kiln f) Brick kiln piled up with 100 thousand green bricks and a layer of burnt clay bricks as sheathing and basis

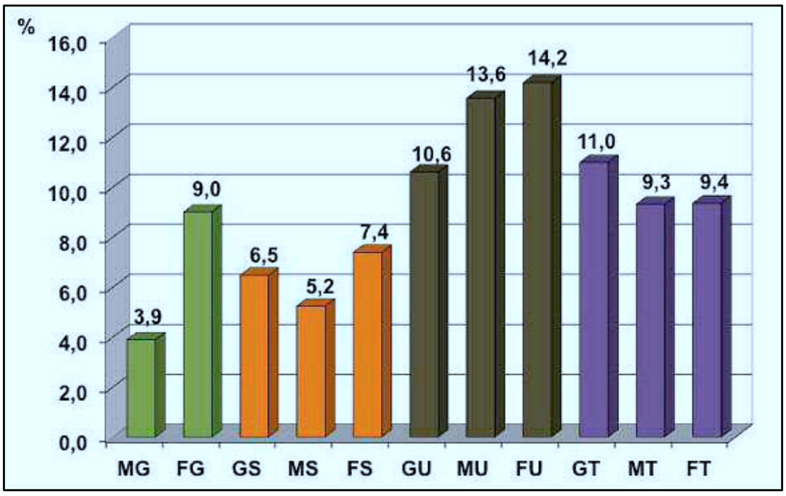
Figure 8: a) Long shafts filled with coal and enable the air circulation in the kiln b) Salt and rice husk is distributed along with coal c) Coal is distributed between each layer to guarantee the burning of all bricks d) The gap between the green bricks and the sheathing is filled with rice husk e) The piled up brick kiln ready for the burning process f) The area of the brick kiln after the burning process and removal of bricks

4.2 Green Brick Analysis, Material, Energy and Area Consumption of the Brick Industry in the Study Area

4.2.1 Grain Size Analysis

Figure 9 shows the results of the grain size analysis (GSA). The graph shows the average grain size distribution of the three analysed green brick samples. 12,9% of the raw material is gravel with a grain size >2mm, represented by the green bars. 19,1% is sand with a grain size between 2mm and 0,063mm, represented by the orange bars. The largest fraction is silt with 38,4% and a grain size between 0,063mm and 2µm, represented by the brown bars. The second largest fraction is clay with 29,7% and a grain size <2µm, represented by the purple bars.

Figure 9: Average grain size distribution of the three green brick samples from the study area



4.2.2 Soil Mineralogy and bound Elements

The simultaneous thermal analysis (STA) of the three green brick samples revealed that the raw material experiences a weight loss of 11,6%, 11,7% and 13,9% if heated up to 1000°C, which results in an average weight loss of 12,4%. The graphs for the STA of the three green brick samples are given in appendices 1-3. The average value for SOM present in the samples is 2,8% of the total soil mass, including rice husk added as internal fuel.
The XRD analysis confirmed the presence of Smectite, Zeolite, Kaolinite, Layer-silicates, Quartz, Feldspar and Hematite in all three green brick samples. The results of the XRD for each of the three samples are provided in appendices 4-6.

4.2.3 Material Consumption per produced Tonne of Bricks

As shown in table 2 and figure 10, water has the greatest share among the consumed materials with 46,8% and 1218,82kg/t of produced bricks. Soil as the basic raw material for bricks has the second largest share of the used materials with 46% and 1196,24kg/t. 3,6% and 94,12kg/t can be attributed to sand extracted from rivers or the sea[13]. The fuel for the brick kilns in the study area is provided by 1,4% Indian coal, 0,3% Australian coal with a total of 46,69kg/t and

[13] At least one of the brick kiln managers within the watershed is also involved in sand mining, did not make any closer comments on that.

1,8% rice husk with 42,33kg/t. Salt has a relatively small share with 0,1% and 3,75kg/t[14], while diesel and petrol provide 0,43kg/t less than 0,1% of the consumed materials. It is interesting at this point to look at the relatively small share of materials that is provided by energy carriers (3,6%) considering the fact that they provide all the energy used.
To highlight the significance of soil for brick production, and also because water is considered a free resource that is bound into its own cycle, it is excluded in figure 11. The availability of water should not be underestimated and will be discussed later in this study, but the share of now 86,46% shows the high significance of soil as the raw material for brick production and illustrates in a vivid way the net export of a crucial resource from the watershed for the urbanisation process of the MMR. In figure 11 diesel and petrol are now also represented with 0,03%.

Table 2: Material consumption per produced tonne of bricks

MC - kg/t brick	
Water	1.218,82
Soil	1.196,24
Sand	94,12
Rice Husk	42,33
Coal	46,69
Salt	3,75
Diesel & Petrol	0,43
Total	**2.602,38**

[14] Regarding brick kiln managers explanations, salt is used to give the bricks the desired red colour and the amount used depends on the requirements of the customers and determines the price of the end product.

Figure 10: Material composition of brick production

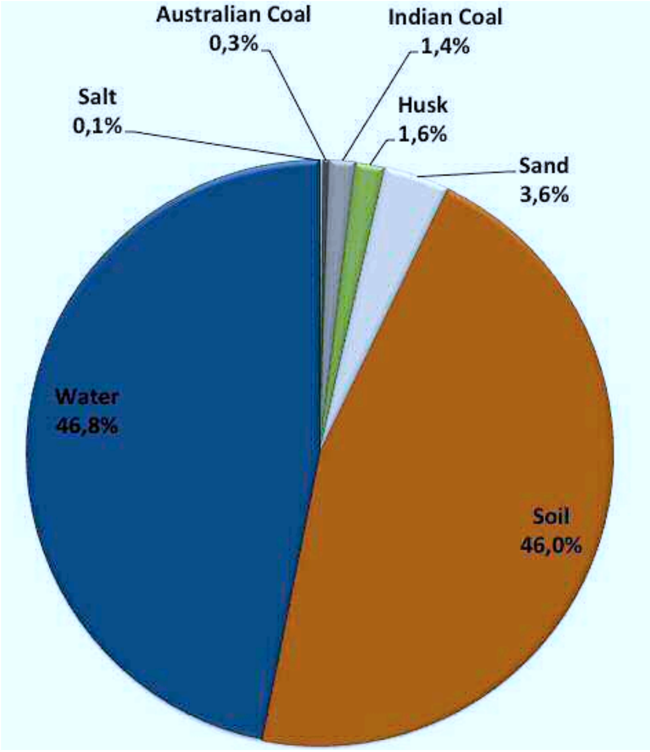


Figure 11: Material composition of brick production excluding water

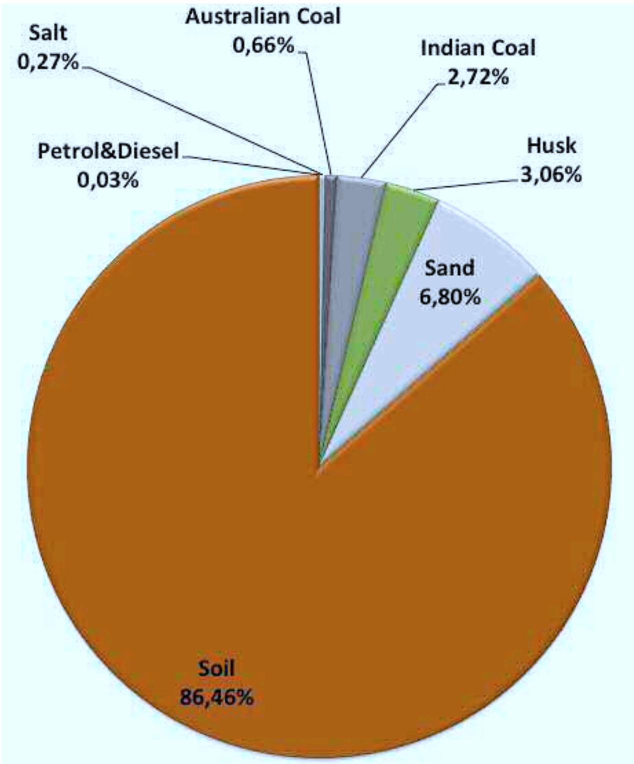
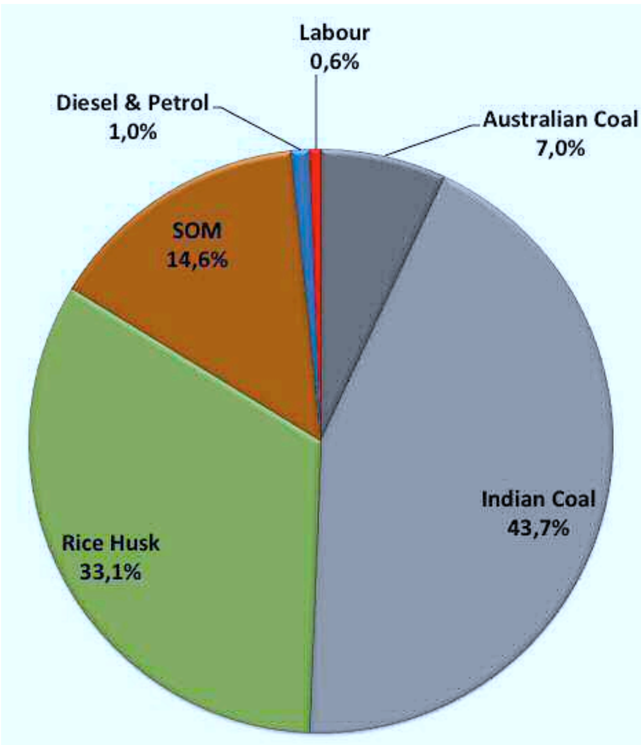


Table 3 shows values in Megajoule per produced tonne of bricks and figure 12 the energy share in percent provided by the different commodities. 50,7% of the energy is provided by coal (7% Australian and 43,7% Indian coal) with a total value of 970,10MJ/t. Biomass provides 48,6%, consisting of 33,1% rice husk with a value of 634,94MJ/t used as external and internal fuel, and 14,6% SOM with a value of 280,07MJ/t. The smallest share is provided by 1% diesel and petrol for transport and the water pump with a value of 19,65MJ/t and 0,6% human labour with a value of 11,32MJ/t. In total the production of 1t bricks consumes 1916,08MJ.

Table 3: Energy consumption per produced tonne of bricks

EC - MJ/t brick	
Coal	970,10
Rice Husk	634,94
SOM	280,07
Diesel & Petrol	19,65
Labour	11,32
Total	**1.916,08**

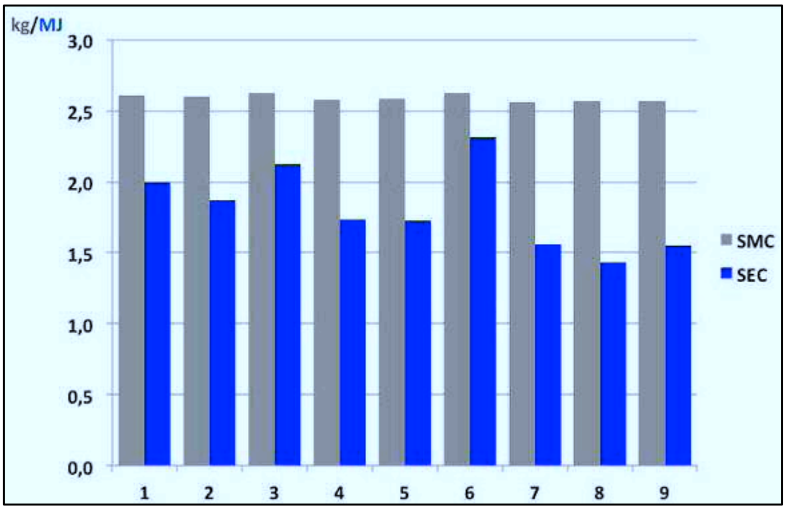
Figure 12: Energy composition of brick production



4.2.4 Deviations between the 9 Kilns in Material and Energy Consumption

Figure 13 shows the differences in material and energy consumption between the 9 observed brick kilns in the study area. The specific material consumption (SMC) and specific energy consumption (SEC) provide values for material consumption (kg) and energy consumption (MJ) for the production of 1 kg of bricks. Numbers 1 to 9 represent the 9 studied brick kilns with grey bars for SMC and blue bars for SEC. While the SMC values range only from 2,56 to 2,62kg/kg, there is a large variation observed in the SEC of the different brick kilns ranging from 1,43 to 2,31 MJ/kg. These differences in SEC are mainly attributed to the large differences in the quantity of rice husk used by the nine kiln managers as additional fuel, which explains why it is not reflected in the SMC in the same extent due to the low bulk density of rice husk.

Figure 13: SMC and SEC of the nine observed brick kilns in the study area



4.2.5 Material and Energy Consumption of the entire Brick Industry in the Study Area

In the season 2013/2014, nine brick kilns of different sizes were operating in the watershed, ranging from 20 to 265 labourers with an annual output from 1324,58t to 18012,92t bricks. The cumulative numbers of all operating brick kilns are given in figure 14 and table 4 and help to understand the overall dimensions of the industry in the study area. In the entire watershed 650 labourers were producing 19,47 million bricks with a mass of 41,37kt and a total material expenditure of 107,65kt. The material expenditure is therefore 2,6 times higher than the production.

Figure 14: Brick production and material consumption of the brick industry in the study area in the season 2013/2014

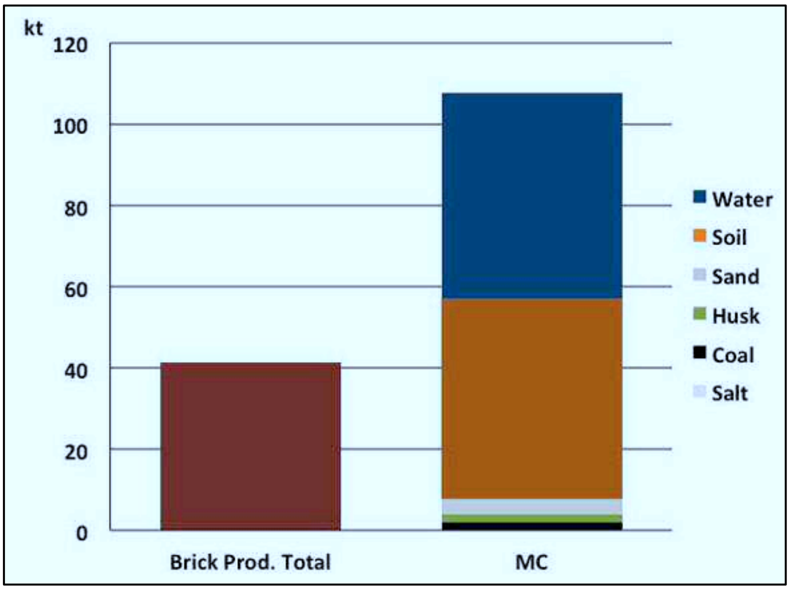


Table 4: Material consumption of the brick industry in the watershed in the season 2013/2014

MC Watershed 2013/2014	Labourers	Nr	650
	Brick Production	Nr	19466666
	Brick Production	kt	41,37
Water	Water	kt	50,42
Minerals	Soil	kt	49,48
	Sand	kt	3,89
	Salt	kt	0,16
Biomass	Rice Husk	kt	1,75
Fossil Fuels	Indian Coal	kt	1,56
	Australian Coal	kt	0,38
	Diesel & Petrol	kt	0,018
Material Consumption total		kt	**107,65**

The total EC of the brick industry in the watershed in the season 2013/14 is shown in figure 15 and table 5. The biggest share is supplied by coal with 5529GJ Australian and 34601GJ Indian coal while rice husk provides a relatively large amount of energy with 26265GJ. SOM provides 11585GJ while diesel and petrol provides 813GJ and labour 468GJ. The total energy consumption of the industry in the watershed in the season 2013/14 is 79262GJ.

Figure 15: Energy consumption of the brick industry in the watershed in the season 2013/2014 in categories

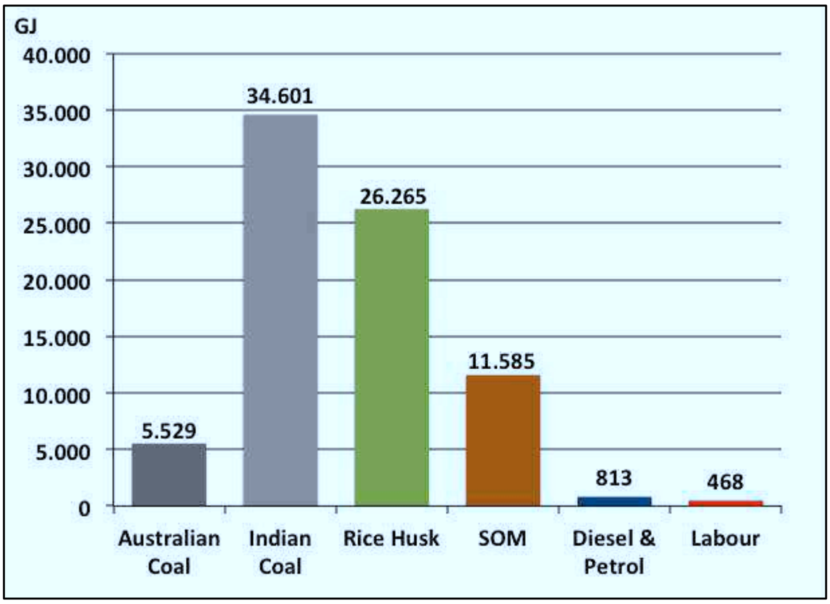


Table 5: Energy consumption of the brick industry in the watershed in the season 2013/2014

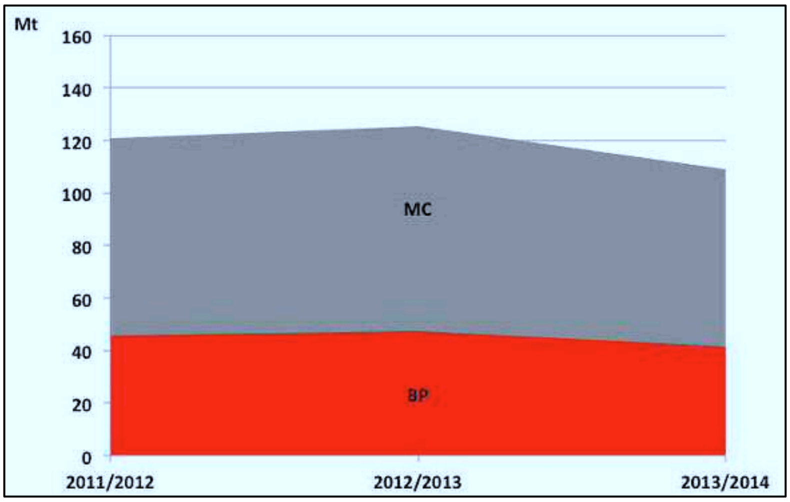
	Category	Unit	Quantity
EC Watershed 2013/2014	Labourers	Nr	650
	Brick Production	Nr	19.466.667
	Brick Production	t	41.366
Fossil Fuels	Indian Coal	GJ	34.600
	Australian Coal	GJ	5.529
	Diesel & Petrol	GJ	812
Biomass	Rice Husk	GJ	26.265
	SOM	GJ	11.585
Human Labour	Labour	GJ	468
Energy Consumption total		GJ	**79.262**

4.2.6 Material and Area Consumption in the Study Area in the last 3 Seasons

Data from the last three seasons shows how the production developed over time. Figure 16 shows a total brick production of 46Mt in 2011/2012, peaking at 48Mt in 2012/2013 and declining to 41Mt in 2013/2014. The material consumption is 2,6 times higher than the annual brick production and follows the same pattern.

Husk, soil and water are the only resources that are extracted from the watershed. The rest is imported from other regions. While husk is a cheap and abundant by-product of the rice production, the depletion of water and soil, which together provide 92,7% of the materials, has direct effects on the availability of these resources. While water is extracted from ponds or the rivers, soil is mainly depleted from agricultural areas, specifically paddy fields. During the season 2013/2014 in the entire watershed area, soil with a volume of 43800m^3 was extracted, which then affected an area of approximately 14,37ha[15]. Figure 17 shows the size of area which was annually affected in the last three seasons, starting with 15,9ha in 2011/2012, peaking at 16,51ha in 2012/2013 and going down to the aforementioned 14,37ha in 2013/2014. The exact values for brick production (BP), material consumption (MC), energy consumption (EC) and area consumption (AC) are given in table 6.

Figure 16: Material consumption (MC) and brick production (BP) in the watershed in the last 3 seasons



[15] The soil samples taken from paddy fields close to one of the brick kilns had a total volume of 0,083m^3 and a weight of 91,5kg. In total 36 green bricks were moulded from the soil sample resulting in a value of 225m^3 soil for 100000 bricks. It is assumed that the depletion level for soil is one foot (30,5cm) for most of the areas and so 225m^3 soil extraction would affect an area of 738m^2. The area calculations in this chapter are based on the same calculations.

Figure 17: Area consumption (AC) in the watershed in the last 3 seasons

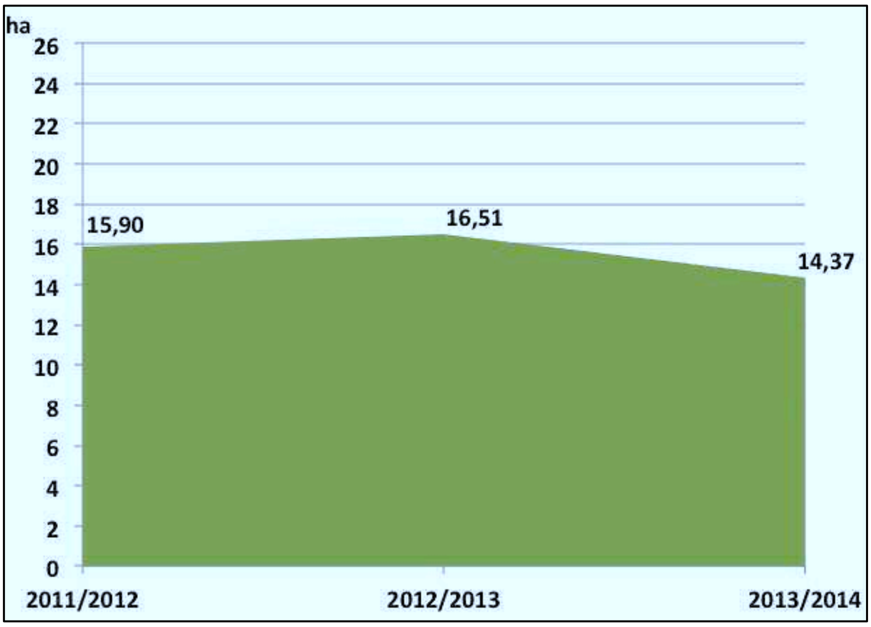


Table 6: Values for brick production (BP), material consumption (MC), energy consumption (EC) and area consumption (AC)

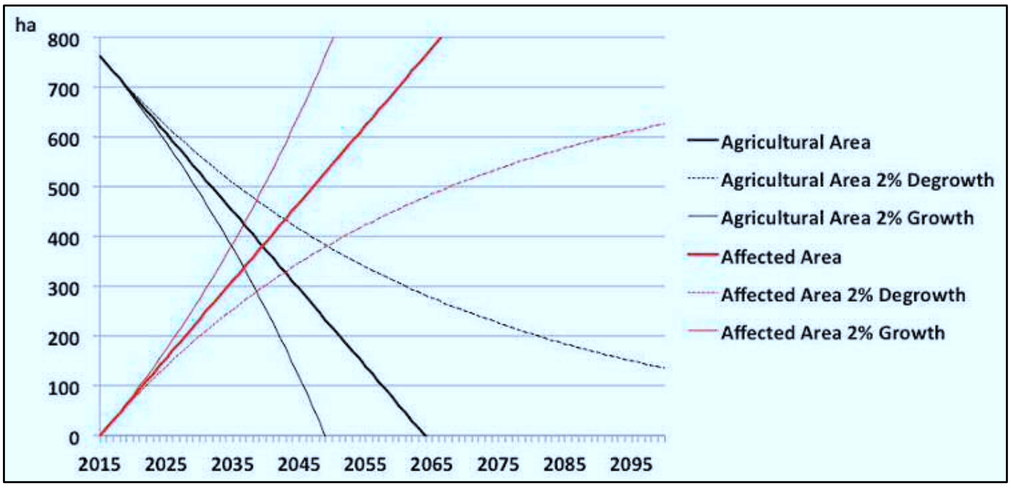
Season	2011/2012	2012/2013	2013/2014
BP (t)	45.776,95	47.534,04	41.366,67
MC (t)	120.772,07	125.403,52	109.037,45
EC (GJ)	89.966	93.316	80.585
AC (ha)	15,90	16,51	14,37

4.2.7 Scenarios for the Consumption of agricultural Area

Observations and interviews with farmers revealed that in most cases only the upper layer of 1ft (30,5cm) is extracted per season and farmers only dig below that level at once in exceptional situations. Many areas within the watershed are already affected by soil extraction because the brick industry has been operating in the region for many decades. Observations in the area revealed that some areas are depleted close to one meter below the normal level. A good indicator is also the street level which is always situated half a meter to one meter above the paddy fields. If areas lie far below that level it can be assumed that they were dug up for soil extraction. Some of the area defined as "build up area and open land" with 824,65ha in figure 3 is very likely recently dug up area. The defined 762,92ha used for agriculture is area which was actively used for no other purpose than for agriculture while the satellite image was taken. It can therefore be assumed that the agricultural area was once larger and is shrinking with the on-going depletion of soil for the brick industry. To estimate how long the excavation of fertile agricultural soil can be carried out in the future before the whole

agricultural area in the watershed is affected[16], a model with three scenarios on the basis of 762,92ha of available area and an annual average depletion rate of 15,59ha was outlined.
The three scenarios in figure 18 help to understand how the brick production affects the area in the watershed presently used for agriculture from 2015 to 2100. The black lines show the available unaffected agricultural area starting with the present available 762,92ha, while the red lines show the increase of affected area through soil extraction.
Scenario 1: The brick production in Tansa Valley will not change in terms of production quantity and follows a linear and stable trend of the last three seasons. In this scenario half of the agricultural area will be affected when the bold red and black solid lines meet in 2039 and the whole area will suffer from the brick industry when the two lines exceed the maximum available area by 2064.
Scenario 2: The brick production in Tansa Valley will increase its production by an annual growth rate of 2% based upon the average production numbers of the last three seasons. This development is represented by the thin red and black solid lines, which show that half of the agricultural area will be affected when they meet in 2035 and all of the area will face consequences when they exceed the total available area in 2049.
Scenario 3: The brick production will decline by 2% per year based on the average production rate of the last three seasons. This could be possible through development in the sector of construction materials and alternatives to burnt clay bricks, which would consequently result in a decline in demand. It could also be possible through alternative raw materials for brick production or changes in the implementation of the laws. In this scenario, represented by the dashed red and black lines, half of the area will be affected when they meet in in 2053 and soil excavation for brick production stops before all the area will face consequences.

Figure 18: Three scenarios for affected agricultural area in the watershed under different development paths of the brick industry



[16] Affected means that at least 30,5cm of topsoil has been removed from a certain area.

4.2.8 Brick and Soil Consumption for a 20 Floor Apartment Building in Mumbai

Figure 19 shows the building photographed in Mumbai and used as an example for a 20-floor apartment building in the MMR. Figure 15b and c show the dimensions of 0,25m^2 brick wall and relations of bricks and concrete fugues. These measurements served as basis for the calculations of the total brick consumption of 1m^2 brick wall. Figure 20 shows the floor plan and figure 21 the 3D-model outlined for a flat with a total of 82m^2, which requires a total of 8,32m^3 of fired bricks with a size of 21,5x10x7,5cm and a volume of 1612,5cm^3 each, which results in a total of 5160 bricks. Assuming that each of the 20 floors has 6 flats and that each of the 3 ground floors require 80% of the bricks of a floor with flats, the total brick requirement of the apartment building shown in figure 15a is approximately 700000 bricks. If only 1ft of agricultural land is extracted, the total number of bricks required for the apartment building results in an affected area of 0,5ha of agricultural land in addition to the 500m^2 basal area required for the building itself.

Figure 19: a) A typical 20-floor apartment building in the MMR with bricks as fillings for walls b+c) Brick walls with bricks of the same size as produced in Tansa Valley and measurements of concrete fugues

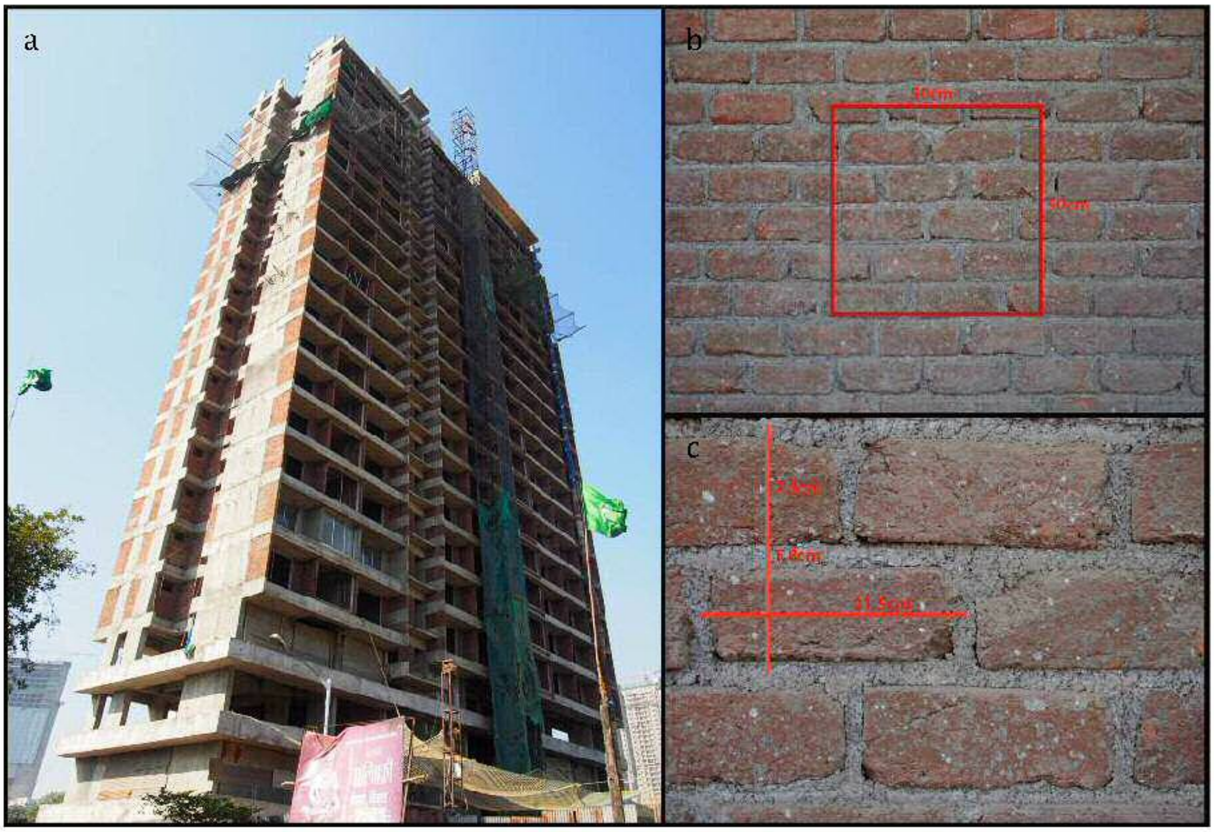


Figure 20: Floor plan of a 82m^2 flat from a 20-floor apartment building in Mumbai

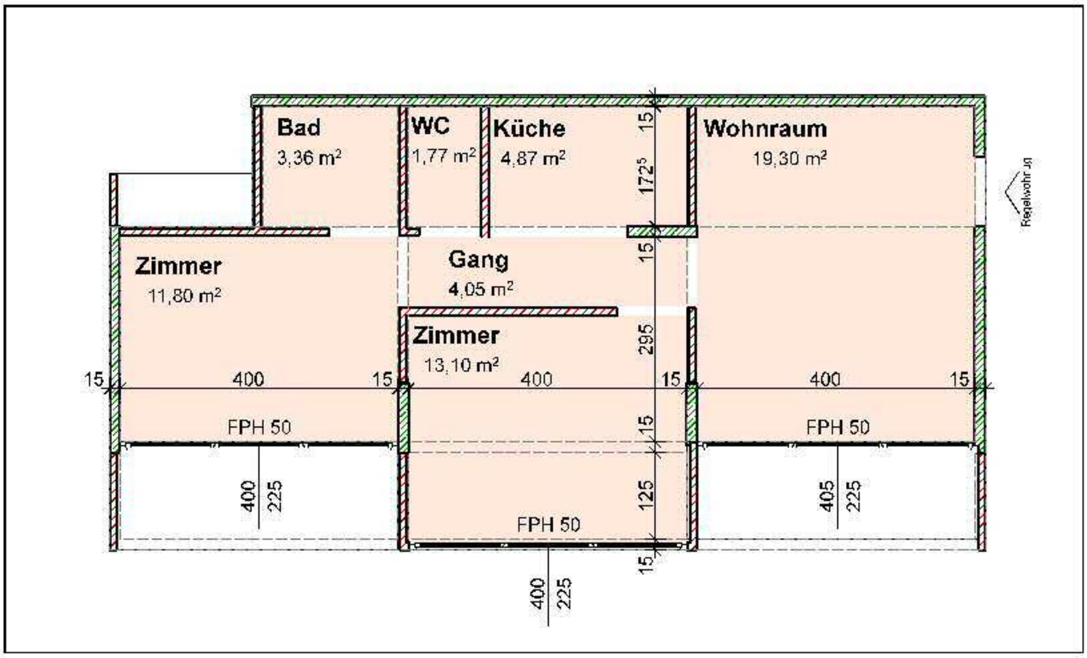
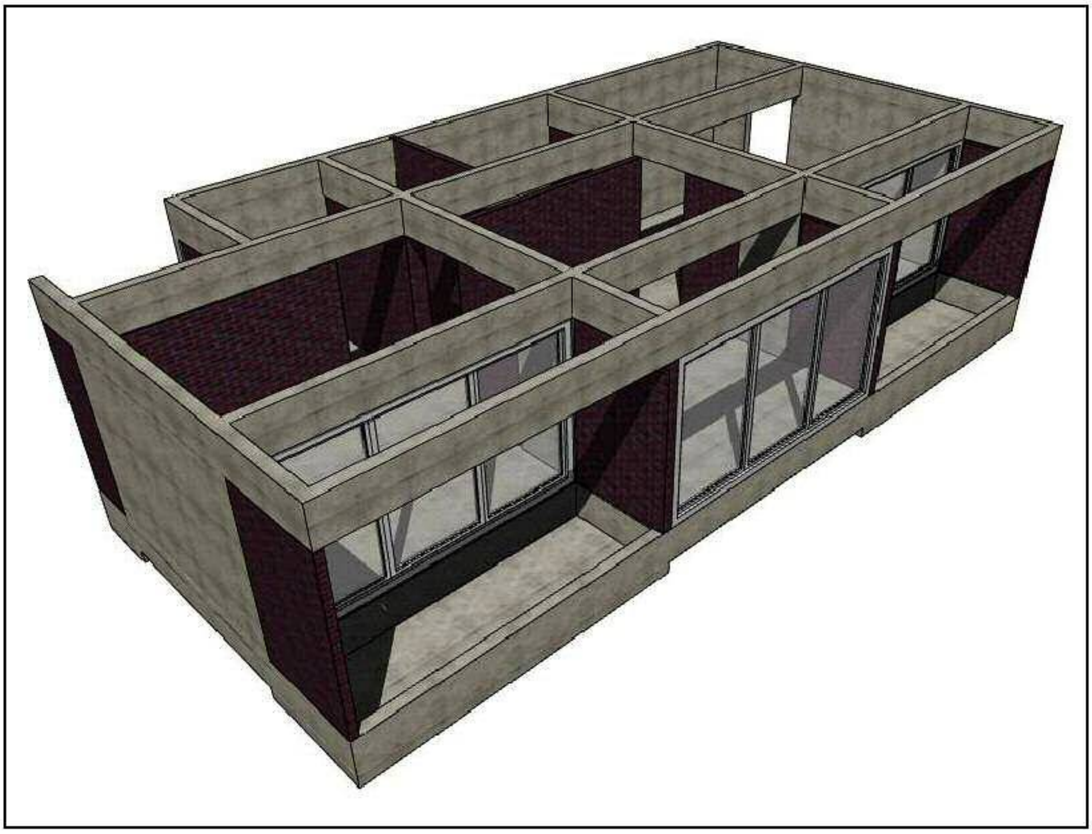


Figure 21: 3D floor plan of a 82m^2 flat from a 20-floor apartment building in Mumbai



4.3 The regional, social and economic Context of the Brick Industry in Tansa Valley

The conducted interviews with six farmers and one agricultural consultant all from the villages in the watershed give an insight into the basic realities. The interviews reveal personal opinions and perspectives on agriculture and finances, brick making, soil and environmental issues, water and irrigation topics. The interviews were carried out with two farmers who sold soil to brick manufacturers, three farmers who don't sell their soil and one farmer who is running a brick kiln in the dry season. The interviews help understand the reasons behind the engagement of the farmers in the brick industry. They also help understand the major problems and concerns of farmers and the agricultural sector in Tansa Valley. This chapter only reflects personal opinions of the interviewed individuals and will be discussed later in this study.

4.3.1 Agriculture and Finances

The land holdings of the interviewed farmers have a total size of 2 to 22ha out of which 1,4 to 8ha are cultivated lands. One of the farmers mentioned that the individual size of landholdings has gone down for some time. Every farmer has paddy fields; paddy rice can be considered the main crop that is only planted in the Kharif season from May to October. Other mentioned crops are onions, chilli, tomatoes, eggplant, okra but also pulses and marigold flowers. Some of them can also be planted in the Rabi season from November to April. Mangos are also common in the region and one of the farmers mentioned he grows 350 trees on 4ha of his land. The government provides tree samplings for free and seeds for crops need to be purchased at the local market, but also home-grown seeds are in use. One of the farmers mentioned that it is necessary to buy new seeds every two to three years because otherwise the yield goes down. There are mainly hybrid seeds in use and traditional seeds are hardly available. Livestock is not very frequent in the study area and only one of the interviewed farmers has had a poultry farm for two years, while another two have a small number of buffalos for milk and labour. For the other interviewed farmers livestock is too risky because animals could get diseases, die and cause financial losses.

Observations in the study area indicate that poultry farming is done by a few farmers but not on a large scale. Buffalos are also common, but like poultry not in every household. With a purchasing price of 70 to 80 thousand Indian Rupees and the on-going costs throughout the year to hold one or more buffalos, it is not profitable for most farmers. Livestock was common in the generations before but many farmers gave it up in the recent decades, while on the other side the meat consumption among farmer households has increased. One of the interviewed farmers mentioned that in former times all the family members were working on the fields but this is not happening anymore and so labourers are required. The numbers of labourers on the fields range from 0 to 20 and are either daily wage labourers or contractors who get paid a fixed amount for a specific work which lasts over several days or weeks. Three of the interviewed farmers invested in machinery and one of them has no labourers for the field. A small manual tractor with an additional trolley set costs approximately 200 thousand INR and the on-going costs are cheaper, but for most of the farmers it is not easy to raise the money for such an investment.

Farmers sell their products to the local markets in the larger villages outside of the watershed and also to middlemen or private traders who then supply the larger markets in urban areas. Two of the interviewed farmers believe that the inaccessibility of the greater markets and lack of transport infrastructure is a problem for the farmers of the region and benefit only the middlemen or traders who push the prices for the products down too low to survive.

Loans are provided either by private moneylenders, cooperative societies or government institutions. The access to government money is not very easy for most of the interviewed farmers, so they approach either the cooperative societies or private moneylenders. Only one farmer with the biggest landholdings and a brick business had no problem concerning the access to money. All of the interviewed farmers had taken loans on their house, their land or as prepayments for future harvests. Subsidies are only given for fertilizers and pesticides and cover 50% of the expenses. Also here the access does not seem to be equally distributed among farmers. One of the interviewed farmers is also an artist and claimed to have sufficient additional income possibilities. He and the brick manufacturer are the only two individuals among the interviewed who talked positively about their financial situation, but only because they had sufficient additional income from other sources. The brick manufacturer generates an additional income from sand mining and a transport business in Mumbai. He claimed that his financial situation was always good. Additional income is also necessary among the other interviewed farmers while two farmers are dependent on their income from farming alone. Not surprisingly, it was also these two farmers who are selling their soil to brick makers when they feel a financial need. For the next generation farming does not seem to be a very promising option and so investment in their education is a priority. Six of the seven interviewed individuals agree to the statement that there is no profit in farming in Tansa Valley, neither in Rabi nor in Kharif season because the costs are too high, the climate unpredictable and the prices for products too low. The only person who made no comment about it had sufficient income possibilities from other sources and the brick manufacturer lives on his other business but agrees that farming is a total loss.
Only one farmer made a comment about the price he gets for soil, which is approximately 20 thousand INR for 0,4ha of 1ft deep depleted soil (1,4kt), which he sold in one year. All interviewed farmers know about the consequences they have to face if they sell their soil. It is not a problem of awareness but rather a problem of urgent financial needs that drives farmers from Tansa Valley into the desperate position to sell their own source of livelihood. The soil business then improves their financial situation, but only in the short run. The lower production of the following seasons and extended use of fertilizers will then increase the losses they already face in agriculture and leads into a vicious cycle of compensating losses with further sacrifice of their soil.

4.3.2 Brick Making, Soil and Environment

The brick manufacturer revealed that farmers of the region have been operating brick kilns for three generations. The initial investment to start a brick kiln is not affordable for many farmers of the region because the labourers and the materials for production need to be paid in advance, and then it is uncertain when the first bricks can be sold. The financial situation of the interviewed brick manufacturer has been good for many generations, but through the brick business it has improved a lot in comparison to former times. One of the interviewed farmers who is not involved in brick making or mining mentioned that the brick business and sand mining is not as profitable anymore as it was in the last decades and that the demand for burnt clay bricks is declining. He also mentioned that the brick business lost its profitability two to three years ago because of the cheaper machine manufactured concrete bricks on the market. He said that these concrete bricks cannot insolate the buildings from the outer heat in the same efficient way burnt clay bricks do and lead to a less comfortable living climate in the houses. Still the price is the crucial factor for builders to choose one material over the other. It was also mentioned that some of the brick manufacturers of Tansa Valley had invested in machines to produce more bricks at a cheaper price, but the problem was that these machines could not handle the stones and pebbles in the soil and so the machines could not be used and the investment was a failure.

Brick manufacturers in the study area don't use their own soil because they see it as an additional business to farming and don't want to destroy their lands. They are aware that the brick production reduces the productivity of the soil but in the interviewed brick manufacturer's opinion depleted areas fill up again with eroded soil from upper regions through the heavy rains during the monsoon. The depletion of soil is sometimes even seen as a good thing to do because it is believed that the removal of the degraded layers from the fields makes them fertile again. The other interviewed farmers who don't run a brick kiln do not share this opinion. In their eyes the depletion of the upper layer has negative effects on the production and on the whole region. The brick maker was asked if the use of raw clay bricks for building would be possible, but in his opinion the climate in Western India doesn't support the use of raw clay bricks. The monsoon rain would wash the houses away, so burning them is a necessity.

Brick manufacturers use three different kinds of soils; soil extracted from the forests, taken from open land that is not under cultivation and soil from paddy fields. One of the interviewed farmers also mentioned that soil from forests is being stolen and is degrading the forests. The fertile layer has a thickness of about one meter but the upper layer can be considered as the most fertile and depletion of only 1ft (30,5cm) already affects the production significantly. The two farmers who sold soil, but also the brother of one of the other interviewed farmers experienced high losses in yield in the season after the depletion. The fertilizer use increased but still the field was not as productive as before. There is agreement among all interviewed farmers and the agricultural consultant that the depletion of one layer of 1 foot (30,5cm) has negative effects on the productivity of the field. There are also concerns among the farmers that the on-going depletion of soil over many years already changes the whole structure of the valley in the sense that the land becomes a stronger slope down to the river, resulting in landslides and increased soil erosion. The uneven levels of the paddy fields also become a major problem, because the water runs off into the fields on a lower level and extracts soil from the upper fields.

Soil erosion through depletion seems to not be the only problem present in Tansa Valley. Farmers agree that the intensive use of chemical fertilizers and the reduction of traditional farming methods is also degrading the soils and leads to a vicious cycle of using more and more chemical fertilizers each year. In the past, every farming household had livestock and used the manure as a biological fertilizer. Giving up livestock and the change to more productive hybrid variations of crops lead to the extensive use of chemical fertilizers and the scarce availability of the traditional crops of the region. All six interviewed farmers are using chemical fertilizers and mentioned that the yield would decline if they would stop using it. In former times natural fertilizers in form of dried leaves and branches were collected from forests or open land, burned on the fields and dug into the soil. Today, through the abundant availability of governmentally subsidised chemical fertilizers and hybrid variations of seeds, farmers see it as too much of an effort to use traditional methods, especially if there is no profit in farming anyway. Only two of the interviewed farmers use biological fertilizers to a small extent, while two don't use them and two don't even know about them. One farmer described the preparation of a mixture made out of the juice of the Neem plant (*Azadirachta indica*), cow dung and water. The mixture is then applied to the fields every 15 days to protect and fertilize the plants but he uses it only as an additional fertilizer to chemical products. All farmers use chemical pesticides to protect the plants from diseases. Their opinion is that the usage of pesticides has increased over the last decades and was not necessary to such an extent when traditional farming techniques were more in use. Two of the interviewed farmers know about organic farming methods but don't practice them and the overall abundance in the valley is very low. One farmer mentioned that organic methods help to cultivate land that is degraded from depletion or prolonged use of hybrid seeds and chemical fertilizers. He also mentioned that manure is an important cooling agent to control the temperature of the soil. The temperature is also a crucial factor in the study area and one of the farmers mentioned that presence of limestone in the soil is a frequent problem, because it increases the temperature in the soil and if manure is not used anymore the soil loses its fertility.

The comments on laws and regulations on soil depletion revealed that there is a certain amount of soil that can be depleted annually but as no one has any accounts on the amount of soil that is being used, it is also hard to comprehend. Brick manufacturers have to buy permits that need to be renewed every year. As some farmers state, corruption and bribes are common regarding the brick business and soil depletion, but also regarding stone quarries and other mines of the region. All these businesses run under concessions for the purpose of "development" of the region and are therefore being tolerated. The farmers and people who are not connected to these businesses face the negative consequences of this development. One of the farmers mentioned so called "D-Zones", special development zones that should make it easier for companies to purchase land from farmers. He said that profits accrued on the shoulders of farmers who sold their land far too cheap because of the lack of knowledge.

4.3.3 Water and Irrigation

The perception among the interviewed farmers is that the rainfall has become unsteady and unpredictable. If the rain is delayed or does not comply with expectations, farmers have to face consequences of crop failure and financial losses. There are government schemes in place that compensate farmers with 10 to 12 thousand INR per ha, but for small farmers this is not enough to financially overcome the year.

As mentioned in the introduction to the study area, the region on the Konkan coast faces two extremes in water availability. During monsoon season there is enough water for rice cultivation, but in the dry season the rivers, lakes and groundwater levels may get affected by declining water levels. That means farmers who want to cultivate in the Rabi season need to take water from bore wells, from the river, from lakes or ponds. The 1976 built Lohape Lake contains water throughout the year but it is used for the villages upstream for artificial fish breeding and is not beneficial for the villages downstream. The rivers and streams hold sufficient water during Monsoon but fall almost dry during the Rabi season. Only small ponds of water remain in the Tansa River, which are used for either growing vegetables or brick production. One of the interviewed farmers revealed that the river had a much larger water capacity earlier, which was reduced through soil erosion from the land that fills up the riverbed. For at least one of the interviewed farmers the river is also too far away to make any use of its water. For him agriculture would not be possible without a bore-well that draws water from the ground. Two farmers mentioned that they take water from the bore wells. The opinions about the state of the groundwater level are very varied. Two farmers said that they have sufficient water and the groundwater level is stable in a depth of about 10 meters, while in the opinion of one farmer it got reduced drastically in the recent years. The agricultural consultant mentioned that the water level has gone down dramatically in the past 25 years in the dry season from former 10m to currently 120m or more, and that all the villages in the watershed are affected. Three of the six interviewed farmers share the opinion that there is not sufficient water in the region for conducting agriculture throughout the year, especially for rice farming. For the brick manufacturer this was the main reason why he is producing bricks in the dry season and he answered the question if he would stop producing bricks if there was enough water available with yes. One farmer, who said that there are not sufficient facilities in the villages to store the water for the dry season, mentioned ponds as a good possibility and that dams are a problem due to the lack of available space and would also not solve the problem throughout the year. Another farmer said that the available water is not equally

distributed among the farmers of the region. This explains the diversity in the opinions of the individuals interviewed.
It seems that there are no government plans in place to improve the situation in the study area with respect to sustainable development of agricultural activities. The agricultural consultant said that there is a need for more research about the ground water level and that his attempts to make barren lands cultivatable through irrigation and to improve the situation failed because they failed to deliver it to the right government departments.

5. Discussion

5.1 Fuel, Emissions and Energy Efficiency in Brick Production

5.1.1 Biomass and Coal as Fuel for the Kilns

India has the 4th largest coal reserves in the world with 92Gt (Smil 2008) and could provide coal for its contemporary consumption of annually 675,4Mt (EIA 2014) for 136 more years. For India the availability of coal is not a problem, but the high levels of consumption creates problems on the output side by releasing emissions and toxic residues that harm not only the environment, but also the health of human beings in closer vicinity to its combustion.
The brick industry is the largest consumer of coal in India after the steel industry with an annual consumption of 35Mt (Maithel 2013). With 1,7% of the MC it has only a relatively small share among the resources used for brick production but delivers 50,7% of the consumed energy. Brick manufacturers in the study area use a larger share of Indian and a smaller share of lower quality Australian coal as fuel. One brick manufacturer said that he purchases Australian coal for 6000INR/t and Indian coal for 8500INR/t. The heating value of 14,42MJ/kg for Australian coal (USGS 2014) seems relatively low given the fact that most of the steam coals have a calorific value between 20 and 25MJ/kg (Smil 2008), which then fits to the data on Indian coal with an average calorific value of 22,24MJ/kg (USGS 2014). The reasons given by the brick manufacturers in the study area for using Australian coal is mainly to reduce the cost for fuel, which then speaks for a lower quality of Australian coal. As Australian coal accounts only for one quarter of the coal used as fuel in the brick kilns, the difference in the heating value does not have a very large impact on the total EC. Cost is an important factor for the brick manufacturers because it determines the price of the end product, and coal prices in India increased between 2007 and 2012 from 100 to 175% (Maithel and Uma 2012). Using wrong types of coal or wrong mixing ratios can also result in an increase of losses, which is why the choice of the right fuel and ratios is a crucial factor in finding a balance between costs and quality.
Another way to lower the costs is by using industrial or agrarian residues as external or internal fuel. Internal fuel helps to distribute the heat more equally throughout the brick and ensures the vitrification for the entire brick, but should also not be used in too high extent, which could cause cracks or porous bricks[17]. Any material with a calorific value of more than 4,2MJ/kg can be used as internal fuel, which is mixed directly into the green bricks during

[17] Vitrification describes the forming of new liquid mineral phases that turn into glass when the brick cools down and gives bricks the desired strength (Maithel and Uma 2012). Cracks are the consequence of relatively too high temperatures in the brick compared to outer temperatures, which can happen if the internal fuel burns the brick from the inside while the external fuel already expired. Too much or too high portions of internal fuel result in porous bricks and increases the absorption of water (Mueller et al. 2008).

moulding. It was measured that the usage of sponge iron[18] waste with a calorific value of 8,4MJ/kg as internal fuel in Vertical Shaft Brick Kilns (VSBKs)[19] can reduce the amount of external fuel by 60 to 80% (Mueller et al. 2008). The brick manufacturers in the study area save costs by using rice husk as external and internal fuel. Rice husk has a relatively high calorific value with 15MJ/kg (Mansaray and Ghaly 1998; Shen et al. 2012) and is freely available to the farmers in the study area as a residue from rice production. The total share of rice husk in the MC is 1,6% and it provides 33,1% of the consumed energy, which shows that if the 14,6% of SOM are added, energy from biomass is almost as important as coal. Through the high amount of rice husk used as external and internal fuel, brick manufacturers in the study area save significant amounts of coal. The specific coal consumption (SCC) in the study area is relatively low with 46,7kg/t of fired bricks compared to values between 106-237kg/t[20] of fired bricks in Asia's "clamp or other batch kilns" (Heierli and Maithel 2008). Given the fact that 20% of the coal used is low quality Australian coal, the large differences in SCC can only be explained through the use of rice husk as external and internal fuel, the relatively small size of the bricks (21,5x10,5x7,5cm; 2,125kg) and the presence of 12,9% gravel in the raw material. These characteristics lower the time and the energy needed to burn the bricks.

5.1.2 Emissions from Brick Kilns

Due to high fluctuations of emission factors from different brick kilns and technologies (Le and Oanh 2010), the consequences of the emissions from the brick industry in the study area on the environment and human health were not examined in this study. There are various indications in the literature that the emissions from brick kilns have negative consequences on plant growth and human health. The brick kilns in the study area, which have no chimneys, no filters and no facilities to store the toxic residues from the combustion process, fill the air with the distinctive smell of coal and biomass combustion, noticeable throughout the entire study area from December to May. While the emissions stop with the beginning of the monsoon season in June, the toxic residues will slowly distribute in the soil and plants.

Brick kilns release significant amounts of sulphur dioxide (SO_2) and hydrogen fluoride (HF) from coal combustion, methane (CH_4) from biomass combustion and suspended particulate matter (SPM)[21], oxides of nitrogen (NO_x), carbon dioxide (CO_2) and carbon monoxide (CO) from combustion of both (Maithel et al. 2001; Le and Oanh 2010; Maithel and Uma 2012; Skinder et al. 2014). The emissions of hydrogen fluoride (HF) and particulate fluoride (PF) from soil and coal in brick kilns can cause severe damage to the leaves of fruit trees like mangos and other plants like tomatoes (Jha et al. 2008), both grown in the study area. Presence of fluoride was also measured in different vegetables grown in the vicinity of brick kilns in India (Jha et al. 2008). SO_2 has ascertained negative effects on crop plants and trees through direct uptake or acidic rain, while PM and NO_x are also widely reported to have negative effects on plants (Skinder et al. 2014).

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[18] Sponge iron is also called directly reduced iron (DRI) and is produced from iron ore to increase the amount of iron per volume by reduction of oxygen and carbon under high temperatures and gaining a product for conventional steel mills (BusinessDictionary 2014).

[19] A VSBK or Vertical Shaft brick kiln is the most energy efficient brick kiln technology available (Heierli and Maithel 2008; Maithel and Uma 2012).

[20] Heierli and Maithel (2008) refer to an SCC of 32 to 71t/100000 bricks á 3kg.

[21] Suspended particular matter (SPM) are airborne particles from natural or anthropogenic sources smaller than 100µm. PM smaller than 10 µm (PM_{10}) and smaller than 2,5µm ($PM_{2,5}$) can penetrate deep into lungs of humans and animals with negative effects on health. Measurements taken directly at and close to operating brick kilns show a significant amount of PM_{10} and $PM_{2,5}$ generated through combustion processes or depositions through wind (Skinder et al. 2014).

Skinder et al. (2014) reported about widely studied negative health effects from brick kiln emissions of SO_2, PM, CO, NO_x on humans in great detail. Brick kiln workers are exposed to these hazards in an extensive way in the study area because they are working and living only a few meters away from the ignited and emitting kilns. In the study area the houses of the workers are located directly at the sites of the kilns and as there are whole families living there, it can be assumed that also their children are affected. Only one out of nine brick kilns in the study area is located directly in a village, but four out of nine brick kilns are located in the closer vicinity to smaller settlements. Due to the lack of chimneys the emissions from the kilns are emitted very close to the ground and are therefore very likely to affect human health and plant growth in the study area.
Le and Oanh (2010) conducted a comprehensive study about CO, SO_2 and PM emissions in a Vietnamese village with 21 operating batch brick kilns and found high levels of SO_2 and PM in samples in and around the village. The study revealed high variations of emission factors in batch kilns depending on many factors, e.g. the type of fuel used and times of measurements taken during the seven days of one batch. Depending on the sulphur content of the coal in use, SO_2 emissions vary widely and an high ash content and incomplete combustion of coal results in the higher emissions of SMP and CO (Mueller et al. 2008). The fires in the clamp kilns used in the study area are entirely uncontrolled once ignited and only influenced by the amount of coal, the amount of rice husk or other biomass, the distribution and ratio of the fuel within the kiln and the amount of internal fuel used. Incomplete combustion of coal and high variations of emissions during the firing process are very likely.

5.1.3 Energy Efficiency of Brick Kilns

Reduction of emissions can only be achieved if the amount of fuel or the fuel type is changed. Clay bricks require a temperature between 800°C and 1100°C for a specific time to enable the desired mechanical and chemical changes that make the brick more resistant to stresses like e.g. rain or flooding. Mechanical changes take place at different temperatures and consist of the removal of moisture in the brick but also the combustion of organic matter and Calcium carbonate ($CaCO_3$), which explains why 1t of produced bricks consume 1,2t of soil, which is a mass reduction of 16,6%. The results of the STA revealed that the samples reduced mass of an average of 12,4% if heated up to 1000°C. The difference of 4,2% between the two methods in measuring mass reduction can be explained by measuring inaccuracy owed to the difficulties in the field of removing precise soil samples from paddy fields and moulding a specific amount of green bricks. Both working steps contain a range of variation that is tolerable for the investigation of the present study.
To guarantee the desired high temperatures for brick production, various technologies and kiln types are in use in different regions and their performance in terms of resource and energy efficiency shows large variations. The clamp kilns used in Tansa Valley, but also other intermitted kilns like scove, scotch and downdraught kilns, must be newly ignited for every batch of bricks. These kilns are considered as the least resource efficient kilns but they are widely in use because the investment is relatively low at the beginning and they don't require highly skilled labourers to operate the kilns. Continuous kilns on the other hand are more energy efficient and are kept on a constant operational level while bricks are loaded and unloaded. It is either the fire that moves around the bricks (moving-fire kilns) like in Bulls Trench Kilns (BTK) or the bricks that move to different temperature zones within the kiln (moving-ware kilns) like Vertical Shaft Brick Kilns (VSBK) and Tunnel Kilns (Heierli and Maithel 2008).
30% of the brick kilns in India are small-scale intermitted kilns like the clamp kilns operating in the study area in Tansa Valley, while 70% are BTKs with moveable (MCBTK) or fixed (FCBTK) chimney (Singh and Asgher 2005; Maithel 2013). Only 100 VSBKs are estimated

to operate in India and so far no well-functioning tunnel kiln for clay bricks has been reported (Maithel and Uma 2012).

The specific energy consumption (SEC) describes the energy consumed to produce a specific mass of bricks and is an accurate value to compare regional but also technological differences in the brick industry. Values for SEC of different kiln technologies are represented in the literature. Heierli and Maithel (2008) present SEC values for five kiln types with a gross calorific value of 18,8MJ/kg of coal and a single brick mass of 3kg. According to their estimations, intermitted clamp or batch kilns in Asia consume 2,0 to 4,5MJ/kg of fired brick and represent the least energy efficient technology. BTKs in India with fixed or moveable chimney have a SEC between 1,1 to 1,75MJ/kg of fired brick, while modern tunnel kilns in Germany have a SEC between 1,1 to 2,5MJ/kg. The most efficient available technology is the VSBK in India, Nepal and Vietnam with a SEC of 0,7 to 1,0MJ/kg (Heierli and Maithel 2008). Maithel and Uma present SEC values directly measured at one down-draft kiln (a improved version of a clamp kiln) with 2,9MJ/kg[22], three FCBTKs with an average value of 1,22MJ/kg brick, 2 kilns using the Zig-zag kiln (an improved and much more energy efficient version of the FCBTK) with an average value between 0,95 and 1,2MJ/kg and one VSBK with an SEC of 0,95MJ/kg of fired brick (Maithel and Uma 2012; Maithel 2013). Table 6 shows the values for SEC for different kiln types taken from literature and for intermitted kilns also from this study.

Table 7: SEC values for different kiln types withdrawn from literature and the present study

Specific Energy Consumption (SEC) of different Kiln Types in MJ/kg of fired Brick				
Kiln Type	*Heierli & Maithel 2008*	*Meithel & Uma 2012*	*Maithel 2013*	*Present Study*
Intermitted Kilns	2,0 - 4,5	2,9	ns	1,92
MCBTK	1,2 - 1,75	ns	ns	ns
FCBTK	1,1 - 1,5	1,22	1,0 - 1,5	ns
Tunnel Kiln	1,4 - 1,6	1,47	ns	ns
VSBTK	0,7 - 1,0	0,95	ns	ns
Zig-zag Kiln	ns	1,12	0,95 - 1,2	ns

Compared to these values for SEC between 2,0 and 4,5MJ/kg of fired brick for intermitted kilns, the energy performance of the kiln industry in Tansa Valley is more energy efficient than expected with a SEC of 1,92MJ/kg of fired brick. The relatively low SEC in the study area comes as a surprise, given the fact that the share of biomass is relatively high and kilns using only biomass are considered the least energy efficient kilns (Gomes and Hossain 2003). As shown in figure 12 there are large differences between the nine brick kilns in the study area ranging from 1,43 to 2,31MJ/kg, owed mainly to large variations in using rice husk as external and internal fuel. Interestingly those brick kilns using lower quantities of rice husk don't supplement it with a higher use of coal or any other external or internal fuel. Data suggests that these brick kilns accomplish the same results by using less fuel and are therefore more energy efficient.

[22] The downdraft kiln analysed in this study is fuelled only with biomass (fresh eucalyptus branches) and no internal fuel is mentioned (Maithel and Uma 2012), therefore the high SEC is not surprising.

5.2 Consumption of Area and Soil for Brick Production

5.2.1 Area Consumption through urban Expansion

Cities consume area not only on the places they are built on, but also through their consumption of resources from other regions, mainly from the peripheries. While in 1961 India had a total population of 458 million, only 18% were living in urban areas. The picture has changed entirely today with a total population of 1,25 billion and 32% living in urban areas and it is expected that in 2050 with a total population of 1,61 billion, more than half will live in urban agglomerations (FAO 2013). This shows that the urban population is presently growing with an annual factor of 2,4% and in combination with a relatively high GDP growth between 3,8% and 10,3% in the years 2000 to 2013 (Worldbank 2014) it leads to an expected growth rate of the Indian construction sector by 6,6% between 2005 and 2030 (Maithel and Uma 2012). Cities are consuming large areas due to their areal expansion through construction activities alone, but most of the materials used for constructions come from regions close by, which indicates that the area a house, or any other built structure, consumes is in reality much larger than only the area it covers. The 20-floor apartment building outlined in this study consumes an additional area of 0,5ha only for the production of bricks, affecting mainly agricultural areas in the hinterland of the city. Bricks are used mainly as fillings[23] for concrete and steel structures, but also for the informal housing sector on large areas throughout the entire MMR, which is why it can be assumed that this sector also consumes large amounts of burnt clay bricks.

Area consumption is high when a resource gets extracted only from the surface, and so it is estimated that 350 million tonnes of topsoil from the upper 4 to 5 feet (1,2-1,5m) is annually removed all over India by the brick industry (Singh and Asgher 2005). This amount of soil would produce 137 billion bricks with a single weight of 2,125kg such as those produced in Tansa Valley, and could be used to build approximately 200 thousand buildings in the dimensions of the typical 20-floor apartment building outlined in the present study every year. Through the extensive use of surface soil the Indian brick industry affects an estimated area almost twice as big as Salsette, the island Mumbai is located on, every year.

The geological characteristics of the Konkan plateau lead to the assumption that throughout the region deep clay deposits are not, or only very rarely, in existence (Thaware, Kunkerkar, and Shivade 2011) and the information of the Government of Maharashtra on mineral deposits in Maharashtra and Thane district confirms these assumptions (http://www.mahadgm.gov.in). This means that deep clay mining is very likely not possible in the study area and probably also not in the wider region and therefore no available alternative for the depletion of surface soil for brick production.

5.2.2 Use of fertile surface Soil for Brick Production

Soil is the main resource used in the brick manufacturing process along with water in terms of quantity. It is the raw material for bricks and suitable soil for brick manufacturing is therefore the basic requirement for a brick industry to establish in a certain region. 46% of the total material consumption consists of soil taken from paddy fields, open land or forests of the study area and represents the net flow of a resource from a natural system into an urban agglomeration to build up society's biophysical stocks. Soil is at the same time a basis of the world's food production and through the firing process in a brick kiln it changes its physical and chemical composition and cannot be recycled and brought back into its former, for plant

[23] Fillings in this context refers to walls built between the steel and concrete structures of a multi-storey apartment building made out of bricks.

growth essential, condition. As the black cotton and red soils in Tansa Valley are the result of a weathering process and need far more time to rebuild than their current minimization through the extraction allows, the path of the brick industry in Tansa Valley can be considered as highly unsustainable. As there is only a limited amount of soil available, it is only a question of time until the entire area is affected. Farmers already experience negative consequences and the time horizon of the estimated 50 years until all agricultural area is affected is not too far ahead and will be experienced by today's children.

5.2.3 Soil Degradation and Fertilizer Use

It is mainly the upper layer of approximately one meter that is depleted for brick making in India (Singh and Asgher 2005). Observations and interviews with farmers confirmed that in the study area one meter of surface soil is extracted for brick production also. It is this upper layer of soil that holds most of the organic matter and nutrients like N, P, K and S, which is therefore essential for agriculture. Loss of ¾ of soil fertility through brick production was reported from different regions in Bangladesh, where the same methods for topsoil extraction for brick production were used (Khan et al. 2007). All interviewed farmers agree that already the removal of one foot of topsoil reduces the fertility significantly. The farmers who experienced it on their own fields clearly indicated that they had to increase the fertilizer use in the season after and still had a lower yield than before.

The overall situation in the study area paints a rather dark picture. On the one side there are concerns from the farmers that the use of organic fertilizers has gone down for many years and most farmers select hybrid seeds in combination with high levels of chemical fertilizers, which already reduced the soil fertility over many years. Some farmers start selling their soil to brick manufacturers to improve their financial situation and experience a reduction in yield, which again results in an increase in the use of chemical fertilizers. Also farmers who are not selling their soil are affected because as one farmer indicated, the different levels of the fields after soil depletion withdraws water and soil from the higher fields, affecting the production there too. Soil from open land, not used for agriculture, is often extracted down to one meter leading to even lower levels resulting in an entirely uneven landscape and therefore uneven distribution of water. It is important to recall at this point, that rice cultivation depends on flooded fields and if the level of the neighbouring area is one meter lower, it needs sophisticated measurements to prevent the water from running off to the lower levels, carrying soil from higher fields. The use of forest soil from the hills also affects the water availability in the watershed seeing as the reduction of water uptake capacity of the forest soils and disturbance of forest ecosystems result in a lower water yield capacity for downstream regions (Singh and Mishra 2012). The statement of one of the interviewed brick manufacturers that removed soil will be supplemented by soil from other areas through the monsoon rain is very unlikely. Even if the heavy rains lead to an adjustment of the different levels, soil must come from somewhere and the soil formation rate through weathering is far too slow to compensate for the soil lost through brick production. One of the interviewed farmers explained that many years of soil depletion already altered the macro-structure of the watershed by increasing the slope towards Tansa River and therefore increasing the water runoff into the river and consequently the erosion of surface soil.

The results of these processes are short-term benefits for some farmers from brick production and long-term losses for most of the farmers in the study area. If this process is not stopped soon it will result in abundant uncultivable land, livelihood destruction for many farmers and increased migration towards urban centres.

5.2.4 Soil Savings through technical Improvements in Construction Materials

The “Green Brick making Manual” by Mueller et al. (2008) gives a description of *black cotton soils* and describes them as “highly unsuitable for brick making”, while *red soils* are “suitable for brick making with a deep cherry-red fired colour”. It further defines the soil texture for good quality green clay bricks with a share of finer materials like clay and silt between 60% and 70% while coarser material like sand, which is important to prevent cracking during the drying process, should not be more than 30%. Particles >2mm should not be present and also limestone particles have negative consequences on the brick during the firing process (Mueller et al. 2008). The soil used as raw material in the study area have shares of 68% clay and silt and 19% sand suitable to produce good quality bricks if the 12,9% fraction of >2mm is either removed or crushed into smaller fractions. This would then require investments into advanced technologies to process the raw material, which doesn’t seem to be an option for most of the brick producers in the study area because the investment would be too high. If the raw material is only sieved it would then also result in an increase of soil consumption to replace the >2mm fraction.

There are two ways to reduce the material intensity of the brick production. One is to minimize the amount of raw materials used to produce 1kg of brick by producing hollow or perforated bricks (Maithel and Uma 2012). These bricks have an enormous potential in material savings up to 40% and show a good isolation performance, which results in an energy saving potential during manufacturing and in the buildings (Maithel et al. 2001). If a 40% reduction is possible through the production of hollow or perforated bricks, it would reduce the overall soil consumption by 27,1% if the 12,9% >2mm fraction would be removed but then the investment for machinery would even be higher. Therefore hollow or perforated bricks as mainly used in developed countries to reduce the material intensity and increase the isolation performance, seem to not be a satisfying option for the region without any financial support for the brick manufacturers to establish new production methods.

The other way to reduce the material intensity of brick production is by mixing different kinds of supplementary materials into the soil. A wide range of tests and studies has been conducted to assess the potential of additive materials “including fly ash, mine tailings, slags, construction and demolition (C&D) waste, wood sawdust, cotton waste, limestone powder, paper production residue, petroleum effluent treatment plant sludge, kraft pulp production residues, cigarette butts, waste tea, rice husk ash, crumb rubber and cement kiln dust” (Zhang 2013). Covering all these materials would exceed the feasibility of this study, which is why only the possibility of adding fly ash to the raw material before moulding is examined in more detail. Fly ash is known to be popular among the brick producers in the study area and is easily available in Tansa Valley.

Most of the electricity production in India happens in coal-fired power plants generating a huge waste problem by producing more than 110Mt of toxic fly ash every year, opening utilization needs but also opportunities (Dhadse, Kumari, and Bhagia 2008). This means fly ash is an easily available waste product which can be acquired from coal power plants throughout the country. Reviewing results from 4 different studies testing the quality of fired bricks produced with 20% to almost 100% of fly ash, Zhang described that all tested bricks were of high compressive strength and low water absorption and even showed a better performance than common clay bricks. The method of producing fly ash bricks doesn’t require any major changes in the production process and can therefore easily be applied to lower the material intensity of the brick production (Zhang 2013). Cultrone and Sebastán tested fly ash bricks for restoration works and found that the bricks have less density and are therefore lighter than conventional clay bricks without increasing the water absorbance capacity. Fly ash bricks require a higher burning temperature than conventional clay bricks if

the ash particles should undergo a vitrification process but are highly suitable for restorations but also new constructions (Cultrone and Sebastián 2009).
Both methods would help to reduce soil consumption but the problem would persist if the extraction is not reduced to a level close to the renewal rate. Once the soil is gone it is not possible to replace it in an appropriate timeframe.

5.3 Consumption of Water for Brick Production

46,8% of the consumed resources for brick production is water with an annual consumption of 50,42mt in the study area alone. Water seems to be an abundant and freely available resource and no brick manufacturer keeps records about the usage of water for brick production. Also in the literature about brick making in India water is highly underrepresented. This comes as no surprise, considering the fact that if water is used for agriculture, especially for rice, quantities for a region in the size of the study area are much higher than for brick production. Nevertheless a simple calculation reveals that the water extracted for brick manufacturing in one year could irrigate crops with a total seasonal irrigation requirement of 300mm to 800mm in an extent of 4 to 15ha. This cannot create any income alternative for brick manufacturers of course and producing 4 to 15ha more crops per year will not change the economic situation for farmers in the watershed, but it indicates additional indirect consequences of the brick industry on the food production. Adding these numbers to the annual loss of fertile agricultural land in an extent of 15,6ha shows that the quantity of soil and water used for bricks could also serve as resource basis to produce rabi-crops on 19,6 to 30,6ha, which are 2,2 to 3,5% of the total agricultural area in the watershed. It can therefore be seen as a further annual reduction of food production in an environment where water is not abundant in the same extent throughout the year. This example should illustrate that water is also an important resource for brick manufacturing and of relevance to the farmers in the region. Enabling agriculture in the dry season in a large extent would then require a much greater amount of water than annually consumed by the brick industry.
As mentioned in the introduction to the study area, the Tansa River holds larger amounts of flowing water in the months during and after the Monsoon and consists only of water ponds in the dry season. The northern Konkan coast has a high precipitation of more than 2500mm per year (Thaware, Kunkerkar, and Shivade 2011) but most of the rainfall occurs between June and October, which exacerbate the conditions for rabi-crops without storing facilities for rainwater or irrigation measurements and hence makes farmers dependent on one harvest per year (Aneerudha and Sonal 2011). Water can therefore only be taken from the ponds in the river or from the groundwater. As the interviews with farmers revealed, water availability in the dry season is a problem in the watershed and for some farmers the reason to look for a more profitable side business. The brick manufacturer even mentioned that he would stop the brick business if he had sufficient water to irrigate his fields in the dry season. Farmers and also the agricultural consultant mentioned that the groundwater level decreased significantly in the last decades.
Tansa River is not only source of water for people in Tansa Valley but also delivers water from the Tansa Lake, a dammed lake upstream from the study area, over an artificial tunnel system to supply Mumbai's population with drinking water (Brugger 2009). This is another example for a resource that is withdrawn from a city's hinterland, and like construction materials its depletion increases with urban population growth. Another lake upstream, and therefore of potential use for the farmers in the study area, is the Lohape Talao lake located within the watershed. It is fed by abundant small streams from the mountain range and as farmers indicated, is used for artificial fish breeding and agriculture in another village and is therefore also not accessible for all farmers in the study area during the dry season. There is a

small stream from the lake to the Tansa River that only contains sufficient quantities of water during the early months after the monsoon. During the time of data collection for this study, one of the interviewed farmers was building an artificial pond to store the water from the mentioned stream and make it accessible for fields during the dry season. The effects could not be observed at the end of data collection because the dam was not ready then.

6. Conclusion

The production of burnt clay bricks from fertile agricultural soil as it is presently practiced in the study area is highly unsustainable. The removal of one layer of soil already affects the production and farmers experience losses in yield and consequently have to increase fertilizer use. The extensive soil extraction already causes declining yields and in approximately 50 years all agricultural area will be affected in the watershed. Soil degradation is happening in three ways: the removal of fertile soil for brick production, the enhanced erosion processes through the changing morphology of the valley and the increase in use of chemical fertilizers with negative consequences for the fertility of the soil.

Making the brick industry in India more energy efficient is an important task looking at the emissions and environmental consequences the high amount of burnt fossil fuels and biomass causes, but it can only happen aligned with an absolute reduction in the use of fertile surface soil. If development happens only in energy efficiency then it could even increase the pressure on soil resources because a more efficient technology could produce burnt clay bricks for a cheaper price throughout the year and could make them more competitive on the market.

The addition of fly ash to the raw material is an option that is sometimes applied by brick manufacturers in the study area. This option is a possible solution to reduce the pressure on soil stocks and can easily be applied by brick manufacturers, as fly ash is available in the region. The high content of gravel would then still reduce the quality of the bricks produced in the study area and a comprehensive testing would be necessary to determine how the addition of a certain amount of fly ash would determine the quality of the end-product. Considering the large investment for new technologies and the fact that fertile agricultural soil should be entirely replaced by other materials a development of the brick industry in the project region is not advisable. For India it would be important to transfer the brick manufacturing into areas where alternative clay deposits are available and the government must play an active role by supporting industries in regions where they have the least impact on the environment, while completely banning surface soil mining from agricultural areas.

The key for a sustainable transformation in the project region lies in the income possibilities for farmers. The agreement upon the interviewed farmers that there is no profit in farming speaks for itself. The farmers who produce bricks are usually in a better financial situation than most other farmers, which why it is something many people in the region strive for. Those farmers who sell soil to the brick makers are in such a desperate financial need, that they don’t see any other possibility to bridge the season. They are aware that what they do affects their production, but the short-term profits are too compelling for them to think about the long-term consequences. The way forward is therefore improvement of the farmers income, either through better access to the markets, all year production by improving the accessibility to water in the dry season or alternative, environmentally more friendly income possibilities. If the current path continues the basis for food production will be lost forever and present generations already experience the consequences.

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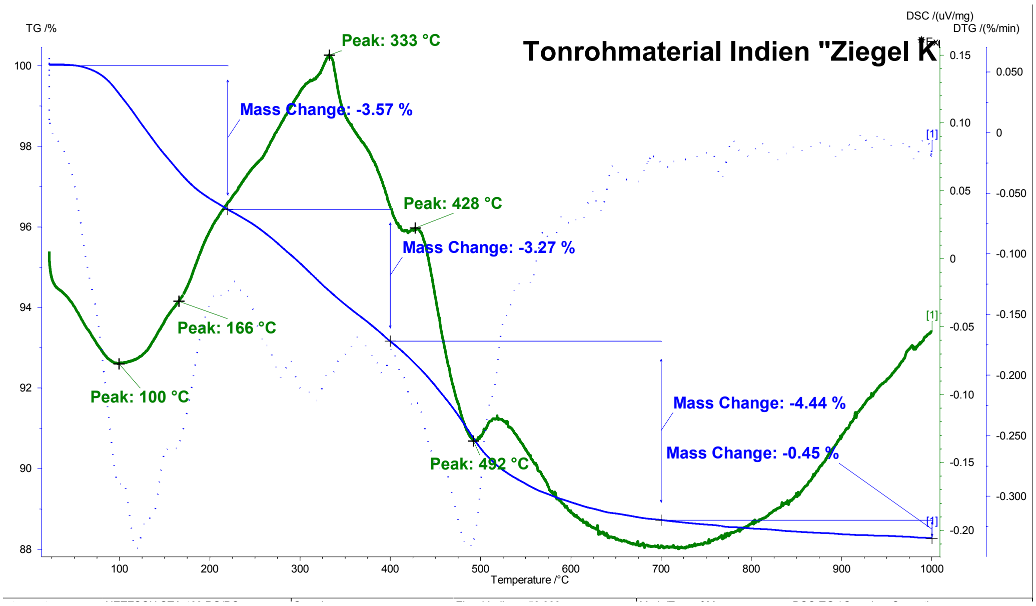
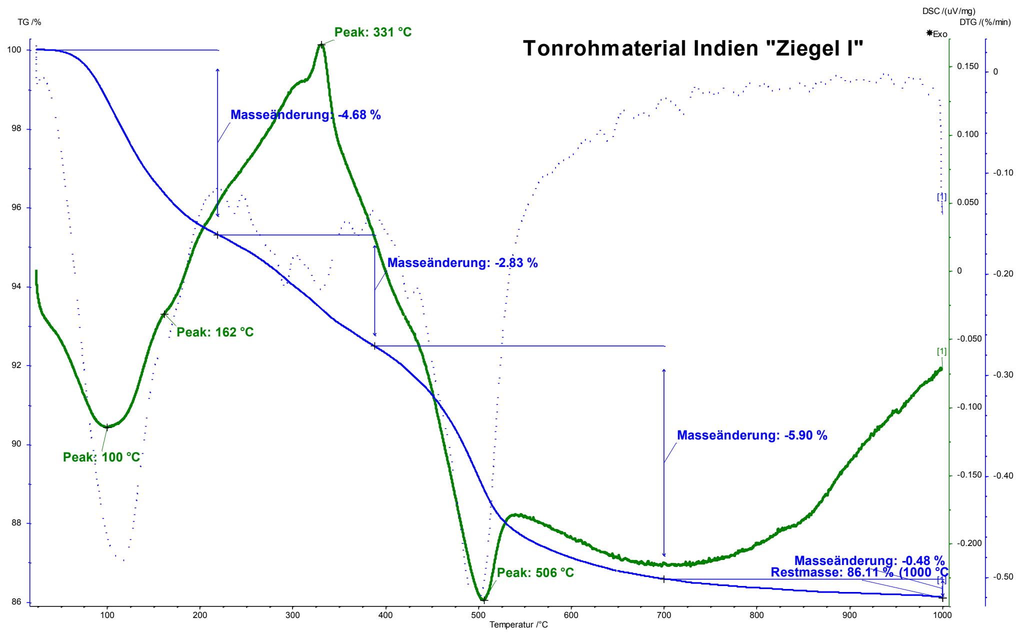
Appendix

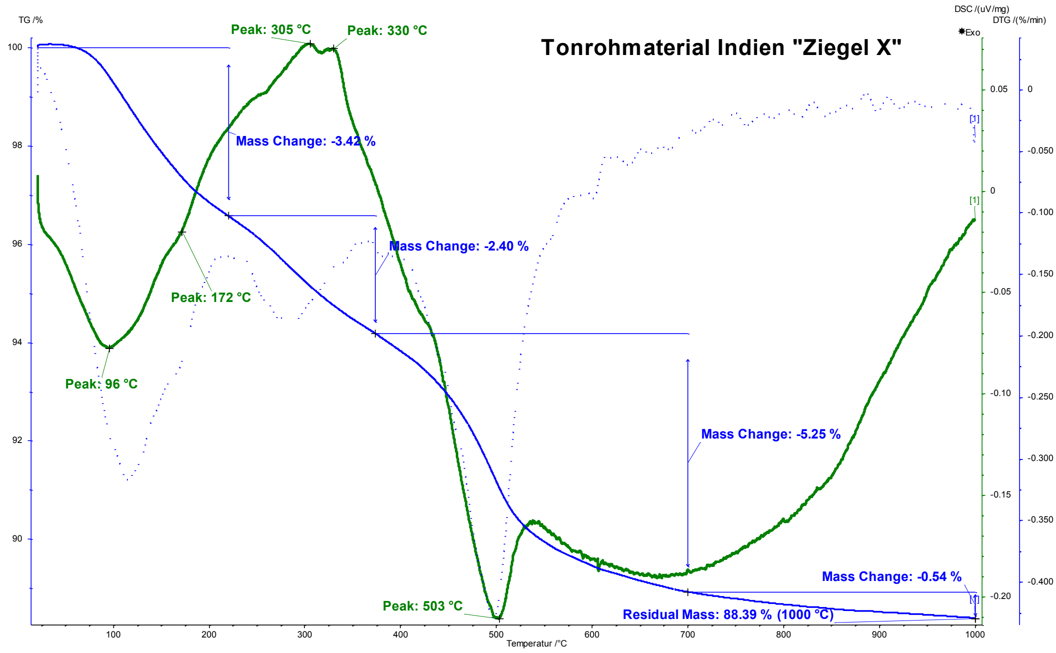
Appendix 1: STA of green brick sample 1 shows a mass reduction of 11,73% consisting of 3,57% elementary bound water, 3,27% organic compounds, 4,44% Calcium carbonates and a small reduction of 0,45% between 700-1000°C



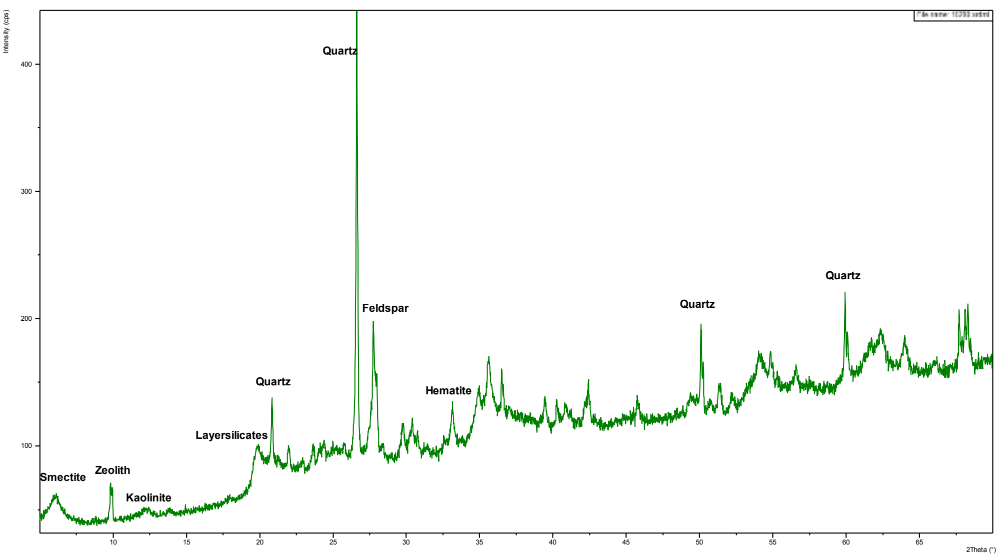
Appendix 2: STA of green brick sample 2 shows a mass reduction of 13,89% consisting of 4,68% elementary bound water, 2,83% organic compounds, 5,90% Calcium carbonates and a small reduction of 0,48% between 700-1000°C



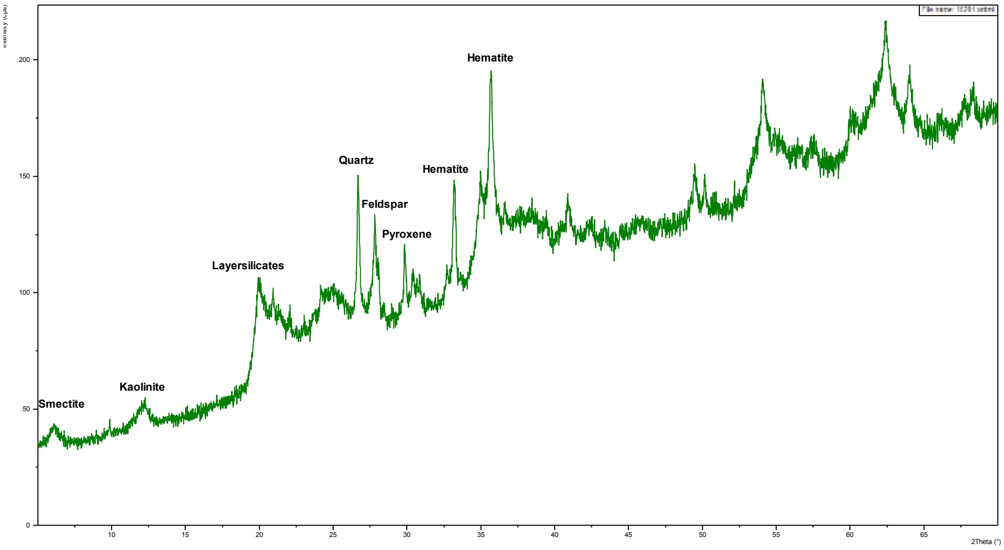
Appendix 3: STA of green brick sample 3 shows a mass reduction of 11,61% consisting of 3,42% elementary bound water, 2,40% organic compounds, 5,25% Calcium carbonates and a small reduction of 0,54% between 700-1000°C



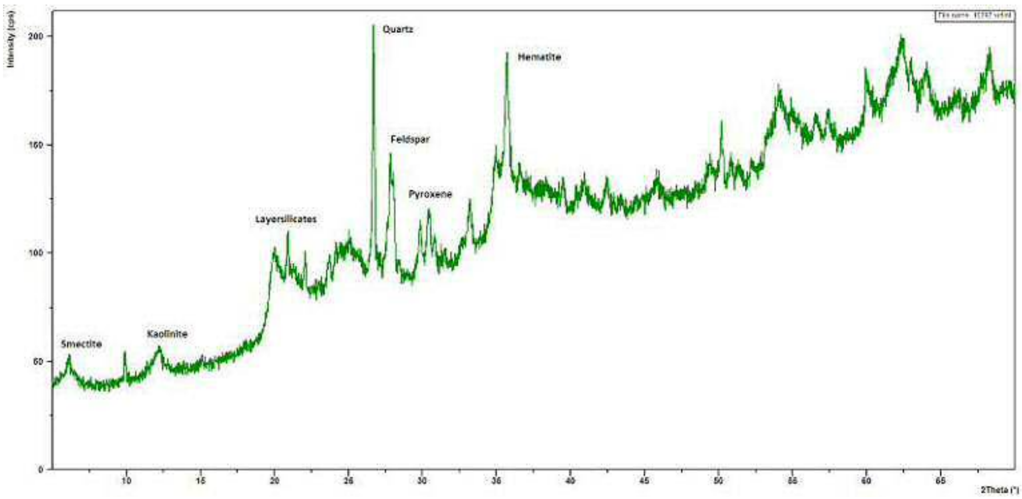
Appendix 4: XRD of green brick sample 1 (fraction <2µm) shows the major components of the clay and silt fractions of the raw material for brick production



Appendix 5: XRD of green brick sample 2 (fraction <2µm) shows the major components of the clay and silt fractions of the raw material for brick production



Appendix 6: XRD of green brick sample 3 (fraction <2µm) shows the major components of the clay and silt fractions of the raw material for brick production



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