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The Truth Inside the Wood

Can Genetic Analysis Help Us Win The Fight Against Illegal Timber Trade?

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Abstract

Illegal timber harvest and trade is one of the main challenges in the context of global deforestation and sustainability. Different governance and self-governance initiatives throughout the history with the aim to regulate global forest commons have received plenty of criticism. This research investigates the potential of genetic timber tracking technologies as a tool to enhance existing systems and achieve legality verification of timber at international, and local context. Literature review, personal interviews, correspondence, observations are the main methods used to identify the limitations of existing systems and context at which genetic methods can assist them. The obtained results are then applied to the context of Costa Rica as a case study analysis.

Ineffectiveness, lack of enforcement resources, corruption, narrow focus, transparency are identified as the main loopholes of the systems responsible for assuring legality of the traded timber. The analysis of genetic timber tracking technologies has led to understanding that species identity, origin of timber and integrity of the supply chain can be verified. Through a modified application of the TIS framework recent regulations in the USA, EU, and Australia are identified as the main drivers and current costs as the main barrier for wide application of the technology.

As for the Costa Rican case, forms and reasons of illegality at timber harvesting, processing, transport and export phases were revealed. The analysis within the PESTLE framework helped to assess overall feasibility of applying the technology at the national legality verification system of Costa Rica. By means of interviews main drivers and barriers for the application of technology in Costa Rica were identified and evaluated. It is argued that despite of a favourable environment and political will, transaction costs and incomplete structure of the system inhibits the application of the technology in the country. Although the technology offers great possibilities, its success will ultimately depend on the local context, readiness of the system and the abilities of the people operating it.

Keywords: Illegal logging, illegal timber trade, supply chain management, genetic timber tracking technologies, DNA Barcoding, Population genetics, DNA fingerprinting

Executive summary

Background

Deforestation is one of the urgent challenges we are currently facing in the context of sustainability: about 20% of all emitted greenhouse gases are claimed to be its direct result. Although there are several reasons of deforestation, illegal logging of timber is the most serious one. Its drivers include growing population size, land use changes for agriculture and increasing demand for timber products. Illegal timber trade is a multifaceted issue involving environmental, economic and social aspects. There have been a number of initiatives to address the issue at international, national, communal, and private levels, each one bringing different focus and governance mechanisms. The CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) (1975), ITTO (International Tropical Timber Organization)(1983), REDD+(2010) at international level, the USA Lacey Act (2008), the FLEGT and EU Timber Regulation (2013), the Australian Illegal Logging Prohibition Act (2012) at bilateral or national level, a number of other national legislations in timber exporting countries, FSC, PEFC and other third party certifications at self-governance level are vivid examples for these efforts. Despite of these initiatives, illegal timber still finds its way into global markets creating the basis for severe criticism along the way. Thus, the most recent approaches are concentrated on improving existing systems and gaining back their legitimacy and stakeholder trust.

Problem definition

Modern timber tracking technologies represent the most recent approach to verify the legality of traded timber and enhance existing systems. Genetic timber tracking methods based on the unique DNA of the tree species is considered the most promising among these. DNA timber tracking can be used in a number of areas: to prove that timber comes from a certain geographic area, designated concession or that it belongs to a certain specie (e.g. to avoid trade of endangered species under CITES). Despite having been demonstrated as a functional and accurate tool throughout the last decade, this method has not been adopted by businesses, certification companies or governments on a large scale and still continues to be implemented only in a limited number of niche areas.

Although it is partly due to an extended period of testing that the technology has had to pass through to prove itself as a standalone method, a general lack of awareness among broad stakeholder groups/audiences about the technology also contributes to its narrow application. This lack of awareness is also generally present in academic audiences. While there are a number of academic articles written on the topic, they are mainly technical and are based on results of DNA tests for certain tree species to identify their species or geographic origin. Despite the fact that information is widely available among area experts, there is no consistent academic literature talking about practicality or feasibility of applying DNA technology in particular phases of supply chain or in national legality verification systems. Thus, the discussion remains rather theoretical and technical in nature, and is generally unavailable to broader audiences.

Research questions and methodology

Proceeding from the above described problem, this research had the purpose of exploring if DNA tracking technologies can be widely and practically used to assist existing systems responsible for assuring legality of the traded timber. To help the research to achieve this aim, the tasks were to assess efficacy of existing forest governance systems and

to identify their limitations. It also focused on identifying the current state of development and dynamics of DNA tracking technologies, as well as its potential for larger and widespread application.

To this end, this study was conducted around following main research question:

RQ1. How (at which levels and context) can DNA timber tracking methods assist existing governance systems? What does the technology offer?

However, understanding the potential of DNA methods and the analysis of the main research question (RQ1) necessitated the following sub-questions to be answered first:

RQ1a. Why does illegally harvested timber find its way into global markets? What are the limitations of existing public and private legality verification systems?

RQ1b. What are the current developments in genetic tracking methods, how does it function, what are the future opportunities, drivers and barriers for its wide spread application?

For the purpose of adding reality check, applying the overall results at the local context and enriching them with new insights from the field, the research also concentrated on Costa Rica as a case country and tried to shed light on the following question as well:

RQ2. What are the main challenges related to combat illegal logging in Costa Rica and how can the technology be applied in the national legality verification system in this country?

Both primary and secondary qualitative data collection methods such as literature and document review, interviews, field visits, observations, correspondence and presentation were employed for the purpose of this research. The overall research was guided by the hypothetical assumption that new technological applications in the form of genetic methods are capable of addressing the identified issues related to illegality in the timber sector. Testing this assumption and analysis of each research question required different methodologies. Limitations of current systems responsible for assuring legal and sustainable timber to the markets (RQ1a) were identified through a literature review, expert interviews and case study reports developed by different NGOs dealing with forest legality. Current developments in DNA technologies and their future potential (RQ1b) were addressed through modified application of the Technical Innovations Systems (TIS) framework. The main research question (RQ1) was addressed by matching identified limitations (RQ1a) with what the technology offers (RQ1b). The analysis of application of DNA technologies in the Costa Rican case (RQ2) was supported by the PESTLE framework.The framework includes Political, Economic, Socio-Cultural, Technological, Legal and Environmental elements, which help to develop an overall image of the environment around phenomena. The results were further classified as drivers and barriers and the value given to each factor was presented in separate table.

Key findings

RQ1a

- ✓ Literature review helped to reveal that global forest governance can be classified mainly as international, (mostly) bilateral legality verification systems, domestic/government, self-governance (forest certification) and communal. Among them forest certification and legality verification systems are considered the most recent ones.
- ✓ Due to complexity of the issue, all initiatives face challenges at different levels in their attempts to address forest illegality and sustainability. Ineffectiveness, lack of enforcement resources, corruption, narrow focus, transparency, etc. are identified as the main loopholes of the systems responsible for assuring legality of the traded timber.

RQ1b

- ✓ Timber tracking method based on genetic methods is considered the most accurate and trustful, as DNA is impossible to falsify unlike usual documentation or tags. Genetic methods can be applied in three areas for the purpose of tracking timber: DNA barcoding for species identification, Population genetics for identifying geographic origin and DNA fingerprinting for Chain of Custody verification. The studies during the last 15-20 years have helped the technology to prove itself as a standalone method.

- ✓ Currently there are several research institutes working on genetic methods for timber and exploring new opportunities. Among those the Thünen Institute in Germany and the Australian Centre for Evolutionary Biology and Biodiversity in Adeilade University are the most specialized ones. NGOs such as WWF and the IEA (International Envistigation Agency) openly support the technology application. Double Helix is the main private organization licensing the technology and offering different services to clients based on DNA analysis of timber. Besides, there are few private companies in the EU, the USA and Australia making use of the technology in their supply chain management. The technology slowly starts to gain interest by certification and accreditation organizations and by governments of EU countries to verify claims.

- ✓ Main drivers and barriers for its wide spread application can be classified as external and internal. New timber regulations and their strict control systems (such as the EUTR (2013) in EU, the Lacey Act (2008) in the USA, the Illegal Logging Prohibition Act (2012) in Australia, etc.), the possibility of green branding and gaining extra markets, increasing pressure from NGOs, future expectations in cost reduction, transformation into highly automated process and the current development of more detailed global databases serve as main drivers for the technology. Unequal enforcement of legislations (especially in EU), limited knowledge of public in large about the technology and its possibilities, current high costs, lack of global reference maps for all species, existence of few laboratories and preference (of mostly domestic governments) to have fast, on time and locally performed control system create major barriers.

RQ1

- ✓ The analysis of case studies on timber illegality (presented in the reports of different NGOs) compared to the possibilities of genetic methods showed that the technology has potential to tackle illegal timber trade on different levels. Those include false geographic origin declarations, extraction of valuable species, and harvesting outside of legal concessions. . Thus, the technology represents a reliable enforcement tool.

RQ2

- ✓ Despite the widely known green image of Costa Rica and its long history of forest conservation, illegal harvest and trade remains important issue in the country. Timber illegality is claimed to comprise 35-40% of totally traded timber in the country.

- ✓ There is a system in place established by the Forest Law of 1996 to ensure sustainable and legal use of forests. However, the system experiences several limitations due to identified technical, financial and structural challenges. Several forms of illegality were identified in the harvesting, processing, transport and export phases of the supply chain. Inability to recognize wood species at different stages, repetitive use of transport permits, incomplete supply chain management, financial dependence of SINAC - the governmental body responsible for surveillance, lack of coordination between police and SINAC, high transaction costs for accessing legality, etc. are revealed to be the main causes for illegality.

- ✓ Currently the country aims to reconsider its forest strategy, increase wood exports and apply new tools for tracing wood and wood products. Hypothetically, DNA methods can enhance existing system through different scales of application.

- ✓ Political, environmental, social, technological, legal, and environmental aspects (PESTLE) helped to shape the overall image around the possibility of applying the technology in the national legality verification system of Costa Rica. The study showed that political will for increasing timber markets and legal consumption of wood in the country, as well as the availability of DNA testing laboratories and potential contribution to sustainable forest management weighted more among other mentioned drivers. Economic barriers such as adding to already existing high transaction costs, to a burden of SINAC's budget, as well as incomplete structure of the system were weighted more than the rest. In general, barriers were mentioned more than drivers for the application of the technology in the national legality system of Costa Rica.

This study concluded that the resilience of the genetic timber tracking technologies is still under question, no matter how appealing it sounds. The effectiveness of DNA technologies to combat illegal logging will always depend on the context of the legality verification system, the readiness of a country, and the capabilities of the individuals operating the technology. As one of the interviewees mentioned, introducing this technology to Costa Rica would be similar to bringing a Formula 1 car to the Amazon forests and attempting to drive it. Thus, although the technology might present excellent opportunities in a standalone fashion and present a perfect match with identified limitations of the systems on a hypothetical level, the context in which it is applied remains important issue if large scale application is to be achieved. However, the Costa Rican case should not be generalized, as the success of the technology depends on each local context, where DNA methods might fit better or worse.

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Abbreviations

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CoC	Chain of Custody
DC	Due care
DDS	Due Diligence System
DNA	Deoxyribonucleic acid
FAO	Food and Agriculture Organization (UN)
FLEGT	Forest Law Enforcement, Governance and Trade
FONAFIFO	Fondo de Financiamiento Forestal de Costa Rica
FSC	Forest Stewardship Council
GFTN	Global Forest & Trade Network
GTTN	Global Timber Tracking Network
HVCA	High value conservation area
ITTO	International Tropical Timber Organization
MINAE	Ministerio de Ambiente, Energía y Telecomunicaciones
ONF	Oficina Nacional Forestal
PEFC	Programme for the Endorsement of Forest Certification
SINAC	Sistema Nacional de Areas de Conservacion
SIREFOR	Sistema de Información de los Recursos Forestales de Costa Rica
UNECE	United Nations Economic Commission for Europe
VPA	Voluntary Partnership Agreements
WBCSD	The World Business Council for Sustainable Development
WWF	World Wildlife Fund

1 Introduction

(Destroying rainforest for economic gain) is like burning a Renaissance painting to cook a meal.

Edward O. Wilson

Deforestation is one of the urgent challenges we are currently facing in the context of sustainability. According to WWF, 12-15 million hectares of forest are lost each year, the equivalent of 36 football fields per minute (WWF, 2015). About 20% of all emitted greenhouse gases are the result of deforestation, a figure that is much higher than the effect of all cars, planes, ships and other vehicles combined, claims Greenpeace (2015). This is quite a shocking number, considering that forests are not infinite and if we continue with the same rate, one day we might end up without any green colour on global maps.

Although there are several reasons for deforestation, illegal logging of timber driven by growing population size, land use change for agriculture and increasing demand for timber products is the most serious one. According to Nature Conservancy (2015) about 30% of globally traded hardwood lumber and plywood is of suspicious origin. Despite all efforts of governments, the international community and the civil society, illegally harvested timber still finds its way into global markets very easily and in most of the cases is sold to unaware citizens under the legal name. WWF and World Business Council for Sustainable Development (WBCSD) define illegal logging as: "harvesting of timber in violation of relevant forestry and environmental laws and regulations" (2005). Besides, illegal timber trade is referred as *"… the procurement, processing, distribution and marketing of products made from wood that has been obtained by illegal sourcing or illegal harvesting and/or are not in compliance with relevant national and international trade laws"* (WWF & WBCSD, 2005).

By its nature illegal logging is a multifaceted issue that involves environmental, economic and social aspects. It destroys the world's precious forests, those that humanity depends on for their survival. It demolishes the habitats of other species of flora and fauna, including endangered ones (such as orang-utans in Indonesia or Siberian tigers in East Russia), it releases carbon that is absorbed by forests or stored in peat lands, it affects water cycles and availability of drinking water in an area, and it leads to landslides and erosion. Besides, illegal logging strongly affects the livelihood of local people who rely on forests by adding to their vulnerability; it involves issues of poverty, indigenous people's rights, human rights, corruption, financing of military and oppressive governments. Illegal logging and trade also distorts wood markets and leads to billions of dollars loss in governmental budgets; it unfairly drags down the prices of global timber and forces the businesses that try to operate in a just and sustainable way to leave the market.[1] The other sad side of the story is that, unaware consumers from all over the world continue buying illegal and unsustainable wood as the hunger for wood products increases annually due to different drivers (e.g. EU's Renewable Energy Strategy).

[1] More details of the effect of illegal logging can be found in reports of NGOs such as Environmental Investigation Agency (EIA), Greenpeace, Global Forest Watch, etc.

1.1 Research problem

Since the 1980s, when issues of deforestation began to be included into the agenda of international organizations, there have been several attempts to regulate the international flow of wood. Establishment of the International Tropical Timber Organization in 1983 and the Intergovernmental Forum on Forests in 1995 were the first serious attempts in this direction. The enactment of REDD in 2010 has become another long-term strategy to save world forests. The New York Declaration on Forests adopted during the Climate Summit in September 2014 represents the most recent international action plan to halt global deforestation. Although on a voluntary basis, in this document participating countries, businesses, NGOs and other institutions pledge to cut natural forest loss in half by 2020, and strive to end it by 2030.

Recognizing their role in timber market, individual countries such as the USA, Australia, as well as European Union have ratified laws in recent years that prohibit the access of illegally harvested or traded wood into markets of these countries. The EU's Forest Law Enforcement, Governance and Trade (FLEGT) initiative (2003), as well as EU Timber Regulation (2013), US Lacey Act (2008) and Australian Illegal Logging Prohibition Act (2012) are the laws passed by these countries and are in the phase of initial implementation. These regulations mainly aim to establish legality verification system as the result of cooperation between timber exporting and importing countries that would inhibit the trade of illegal wood and wood based products.

However, all these international and national efforts have received some criticism along the way as well. In most of the cases these attempts are criticized for being too broad or replicative, by directing limited resources ineffectively to combat the problem. The implementation of these international agreements in developing countries with valuable forests are mostly trusted to national governments, which either lack resources of enforcement or are too corrupt to deal with the problem properly (Contreras-Hermosilla, 2001; Panjer & Greenberg, 2012).

In view of all these successes and failures, private stakeholders and civil society aimed to challenge illegal practices through establishing standards for sustainable forest management and legal timber trade in forms of certification schemes. Widely known FSC, PEFC, etc. are the wood certification schemes that despite being on voluntary basis, today have been translated almost into a license to operate in markets like the EU or the USA. For years these certifications were considered trustful third party organizations that urge their partners to practice sustainable forest management and make them strictly abide by defined principles. However, recent reports of NGOs or academic and news articles present some serious criticism on these certification processes as well[2] (FERN et al., 2008; Greenpeace, 2015).

To address illegal logging, current legislation or certification schemes require maintaining Chain of Custody (CoC), Due Diligence or legality verification systems (e.g. FSC, EUTR and Voluntary Partnership Agreements (VPA) within FLEGT). This documentation is usually done on paper and passed through the entire transaction chain down to the consumer. Existing literature reveals a number of shortcomings in the CoC process. The traceability done through paper documentation is subject to falsification,

[2] The details are discussed further in the main text of the thesis.

modification, loss, etc. Besides, they are believed to be costly and time consuming. Recent NGO reports have also revealed the ways how illegal loggers cheat the legality verification systems placed in different countries and how they continue supplying markets with illegal and unsustainable timber (Global Witness, 2013; EIA, 2013).

Currently there are attempts to address these shortcomings with the help of modern timber tracking technologies. In recent years a number of articles and news reports have been published about promising timber tracking technology that is based on genetic identification of the wood. Depending on the purpose of the technology application, DNA timber tracking can be used to prove that timber comes from a certain geographic area, a designated concession or that it belongs to a certain specie (to avoid trade of endangered species under CITES). Despite having been demonstrated as a functional and accurate tool throughout the last decade, this method has not been adopted by businesses, certification companies or governments on a large scale and still continues to be implemented only in a limited number of niche areas.

Although it is partly due to an extended period of testing that the technology has had to pass through to prove itself as a standalone method, a general lack of awareness among broad stakeholder groups/audiences about the technology also contributes to its narrow application. This lack of awareness is also generally present in academic audiences. While there are a number of academic articles written on the topic, they are mainly technical and are based on results of DNA tests for certain tree species to identify their species or geographic origin. Despite the fact that information is widely available among area experts, there is no consistent academic literature talking about practicality or feasibility of applying DNA technology in particular phases of supply chain or in national legality verification systems. Thus, the discussion remains rather theoretical and technical in nature, and is generally unavailable to broader audiences.

Proceeding from the above described problem definition, this research project will aim to explore how DNA fingerprinting for timber can be widely and practically used to assist existing timber legality verification and CoC systems. To help the research to achieve this aim the tasks will be around assessing the efficacy of existing forest governance systems and identifying their gaps. It will also focus on identifying current state of development and dynamics of DNA fingerprinting technology for timber, as well as its potential for larger and widespread application.

The mentioned tasks will be further tested in the example of Costa Rica as a case study country for the purpose of adding reality check, applying the overall results at the local context and enriching them with new insights from the field. Although not widely mentioned in the literature illegal logging is quite an important issue in this valuable tropical forest country. According to official statistics it comprises over 20-25 % of overall logging activities. There is a strong political will and overall favourable environment for the application of new timber tracking technologies within the framework of "Lines of Action for Implementing the Policy of Forest Development in Costa Rica 2014-2018 " (Lineas de Accion para Implementar la Politica de Desarrollo Forestal de Costa Rica 2014-2018)[3]. Thus, Cost Rica serves as a great case study for analysing the practicality of DNA application in national legality verification system.

[3] The document is still in draft form and under stakeholder consideration

1.2 Research questions and analytical framework

In order to reach the above mentioned aim this study was conducted around following main research question:

RQ1. How (at which levels and context) can DNA timber tracking methods assist existing governance systems? What does the technology offer?

However, understanding the potential of DNA methods and the analysis of the main research question (RQ1) necessitated the following sub-questions to be answered first:

RQ1a. Why does illegally harvested timber find its way into global markets? What are the limitations of existing public and private legality verification systems?

RQ1b. What are the current developments in genetic tracking methods, how does it function, what are the future opportunities, drivers and barriers for its wide spread application?

For the purpose of adding reality check, applying the overall results at the local context and enriching them with new insights from the field, the research also concentrated on Costa Rica as a case country and tried to shed light on the following question as well:

RQ2. What are the main challenges related to combat illegal logging in Costa Rica and how can the technology be applied in the national legality verification system in this country?

The following scheme presents the overall analytical approach of how the research questions are supposed to be viewed and how they relate to each other. While the first three questions are analysed within international context, the same approach is further narrowed down into the context of Costa Rica to answer the last research question.

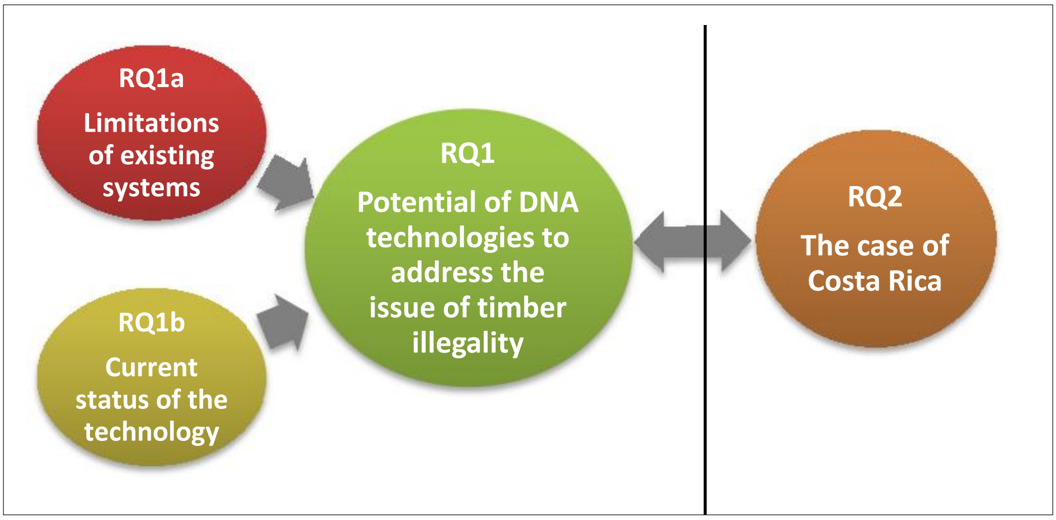

Figure 1. Research questions and their interaction

1.3 Methodology and data collection methods

The overall research is guided by the hypothetical assumption that new technological applications in the form of genetic methods are capable of addressing the identified issues related to illegality in the timber sector and the loopholes in legality verification systems. Testing this assumption and analysis of each research question required different methodologies.

Current developments in DNA technologies and their future potential (RQ1b) is addressed through application of the Technical Innovations Systems (TIS) framework. The approach has been developed by Utrecht University together with other institutes like Chalmers University in Sweden and EAWAG in Switzerland (Utrecht University, 2011). The logic behind the framework is that technological innovation is a complex and collective process and its success or failure largely depends on the context, the system it resides, interaction among stakeholders, and their networks and institutions. Hekkert et al. (2011) define the purpose of TIS framework as "*…analysing and evaluating the development of a particular technological field in terms of the structures and processes that support or hamper it*". Thus, understanding the system around the innovation helps to identify functions, inducement and blocking mechanisms that affect whether it becomes a successful idea/product or not. It is a useful tool for stakeholders to draw conclusions in order to identify the leverage points in policy making, the areas where further technological development is needed, or the ways for creating more market and acceptance. The thorough description of the framework can be found in Bergek et al. (2008). The framework has been modified in the last decade with each author adding new elements to it. For example, Jacobsson & Johnson (2000) apply the framework to explain why employment of renewable energy technologies is slower than the rate and amount of research done in the sphere, Lindmark & Rickne (2005) use it to analyse Swedish mobile internet innovation system and reasons for slow growth, Andreasen & Sovacool (2015) apply the TIS in a comparative study of Danish and American fuel cell research development.

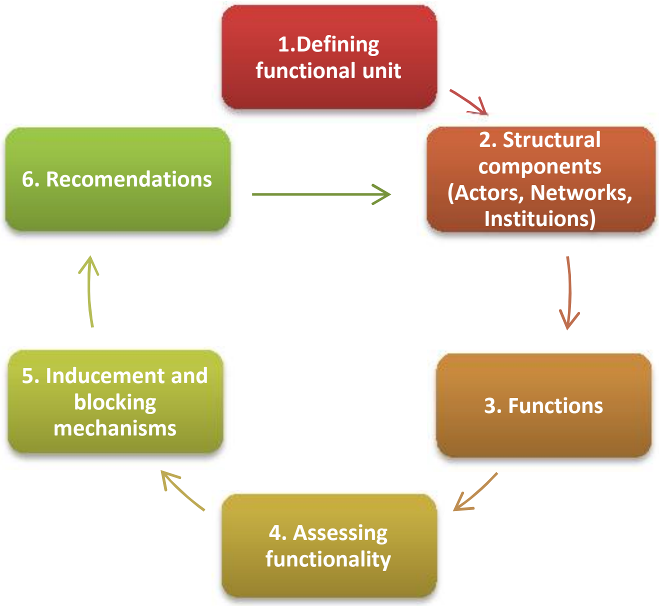

Figure 2. TIS framework and its elements presented by Bergek et al., 2008.

Based on all mentioned characteristics and being applied successfully in several studies, the framework was considered the most appropriate one to help with RQ1b. However, as the main research question of this study (RQ1) has a different focus, the TIS framework is only applied to present a quick overview of the system. Applying the framework in its entire depth (especially concerning functions and functionality analysis) would take too much space explaining the scientific developments in DNA technology and its institutional status and drag away the focus from the case. The Figure 2 describes the elements of the framework explained by Bergek et al. (2008) that this thesis refers to in order to identify the system or "environment" around genetic timber tracking technologies. The more detailed description of how the framework was applied is presented in Chapter 3.

Limitations of current systems responsible for providing legal and sustainable timber to the markets (RQ1a) are identified through literature review, expert interviews and case study reports developed by different NGOs dealing with forest legality. As an outcome, a final list of limitations is presented. The literature review for this purpose was grouped into critical studies about international, bilateral, national and self-governance/private initiatives.

The main research question (RQ1) is addressed through matching the hypotheses developed based on the identified current limitations (RQ1a) with what the technology offers (RQ1b).

For the purpose of making the research context sensitive and enrich the results with insights from the field, the hypotheses were analysed within a case study on the national legality verification system of Costa Rica. The analysis of application of DNA technologies in the Costa Rican case (RQ2) is supported by the PESTLE framework. Similar to SWOT analysis, PESTLE is considered a useful tool for multi-criteria decision making through identification of risks associated with practical application of a certain idea or technology in a certain area[4] (Forbes, Smith, & Horner, 2008). The comprehensive version of the framework involves Political, Economic, Socio-Cultural, Technological, Legal and Environmental elements, which help to develop an overall image of the environment around phenomena through different aspects. It has been widely used to identify the contextual aspects of application of new technologies, for example, in water management systems in Serbia (Srdjevic et al., 2012), in the renewable energy sector in Malawi (Zalengera et al., 2014), in wind energy development in Mexico (Hurtado, 2015), etc. However, unlike the mentioned researches where the framework is applied in a retrospective fashion, in the case of Costa Rica it is used to identify the six aspects of potential future application of genetic timber tracking methods. The aspects are identified through literature review, interviews, observations and other data collection methods that are discussed in the next section. The results are further classified as drivers and barriers and the value given to each factor is presented in separate table.

1.3.1 Data Collection methods

Both primary and secondary qualitative data collection methods such as literature and document review, interviews, field visits, observations, correspondence and

[4] Mostly used by businesses

presentation are employed for the purpose of this research. Data source triangulation[5] is used to address each research question in order to facilitate deeper and more comprehensive understanding and avoid intentional bias. The Figure 3 visualizes data collection methods used for each question. The colour and order of each method change from the most (red) to least (green) frequent used one.

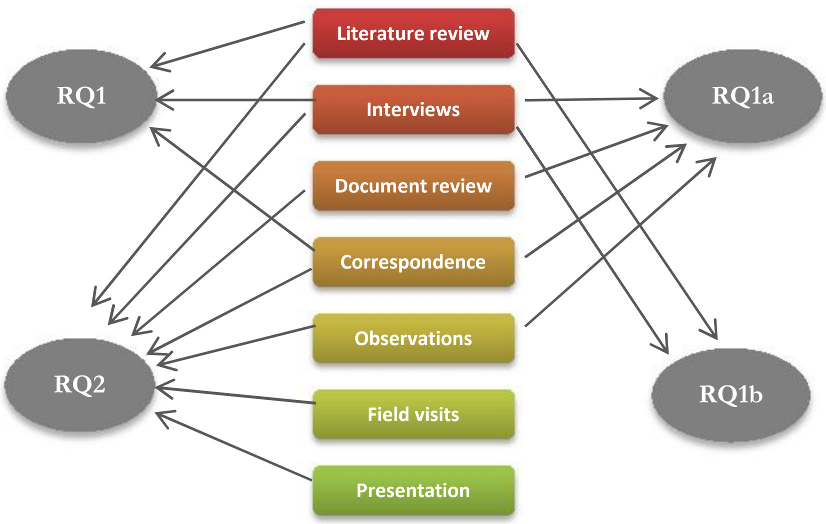

Figure 3. Data source triangulation for each research question

The Initial literature review involved academic and news articles, NGO reports, project reports, etc. with the intention of identifying major actors within the scope. Further review was conducted through search of academic articles with the key words "illegal logging", "forest governance", "forest certification", "wood supply chain", "timber tracking", "DNA for timber", etc. The review laid the basis for understanding existing timber legality verification systems and efforts of the global community in combat against illegal and unsustainable timber trade. NGO reports were of utmost importance for reviewing recorded cases of illegal timber trade and for understanding loopholes in existing systems. However, acknowledging the bias that might be present in these reports, an attempt was made to cross-check their content and arguments with relevant actors during the interviews.

Interviews and written correspondence have helped to validate the information gathered through literature and document review. In order to obtain more accurate information and form a less biased image about the topic, the interviewees were selected based on their experience from different stakeholder groups, including representatives from government, business, timber certification organizations, international organizations dealing with forestry and timber markets, institutions specialized in timber tracking technologies (including DNA fingerprinting), environmental NGOs, as well as local forest

[5] Although the method is called data source triangulation, more than three methods were used to collect the data for each research question.

owners and managers, etc. An example of interview questions is given in the Appendix in the end (See Annex A)

Interviews were conducted in a semi-structured fashion with few pre-determined questions. As the purpose of the research is to understand a new phenomenon not widely known sometimes even among forestry experts, open questions were considered most appropriate to allow experience and knowledge sharing from the context of interviewees, but at the same time without digressing away from the topic.

In general, interviews were conducted around three main topics: 1) national, international, etc. efforts and systems on timber legality and their limitations; 2) genetic timber tracking methods and their application in international context; and 3) Costa Rica and its timber legality verification system.

For the first and second topic, 14 potential interviewees were identified since the very beginning of the research through literature review and basic internet search; they were contacted through email of which only 6 responded back despite multiple attempts. The other interviewees were identified through the snowball method, where some interviewees suggested contacting other relevant actors. For the second topic, the questions were formed mainly based on TIS framework for the purpose of identifying structural elements, functions, drivers and barriers for the technology.

The interviews for the third topic were held during case study visit to Costa Rica within two months[6]. During this period the author did a research internship at a local NGO called FUNDECOR, an organization engaged in sustainable management of natural resources and forests in the country. All interviewees, besides Gulliermo A. Navarro and Carlos Manuel Navarro, were contacted through the NGO. The interview questions were around understanding local context and national legality verification system of Costa Rica in order to identify the limitations of the system and the areas where DNA methods can be applicable. Furthermore, interviewees were also asked to name and rate the main drivers and barriers for the application of technology in the context of Costa Rica[7]. The results were later grouped according to PESTLE framework in order to identify the aspects that might push or inhibit the application of genetic methods (see Chapter 6). Moreover, field visits to forests, discussion with forest owners, observations during audit controls of timber harvesting processes by forest engineers in partner concessions, as well as daily discussions with colleagues in FUNDECOR's office contributed significantly to develop the overall image of the country and of its forest management and timber legality system. In the end of the internship period, the results of the case study were presented to colleagues in the NGO for the purpose of confirming collected data and receiving further comments.

Although none of the interviewees opposed mentioning their names, most of them did ask for confidentiality of some information, as well as for anonymity of their contribution to particular parts of the research. Both face to face and Skype interviews were recorded with prior consent of the interviewees and the records were later used to

[6] From end of February till end of April, 2015

[7] In most of the cases, the interviewees in Costa Rica were not familiar with the technology and its possibilites, thus, prior discussion and presentation of the technology deemed necessary, after which they were asked if they see its application in Costa Rica practical and realistic, as well as reasons of why they think in a certain way.

properly check on given information. Due to time limit or time difference some of them agreed to respond in a written form or through email correspondence. Table 1 presents the names of the contacted people, their positions, the institutions they represent, as well as the method of data collection.

Table 1. Informants and data collection methods

Name	Organization	Position	Expertise	Method
Bernd Degen	Johann Heinrich von Thünen Institute; Federal research Institute for Rural areas, Forestry and Fisheries, Hamburg, Germany	Head of the Institute of Forest Genetics	Forest Genetics	Personal interview, field visit, observation
Darren Thomas	Double Helix, Singapore	Managing Director	Chain of Custody	Online personal interview
Sebastian Schrader	European Forest Institute, Barcelona, Spain	Legality Assurance Systems Expert	Legality assurance of timber	Personal Interview
Jukka Tissari	FAO Forestry Department, Rome, Italy	Secretary of the FAO Advisory Committee on Sustainable Forest-based Industries Forest Economics, Policy & Products Division	International forest policy	Email correspondence
Marius R.M. Ekué	Bioversity International, Global Timber Tracking Network (GTTN) Serdang, Malaysia	Scientific Coordinator, Identification of Tree Species and Geographic Origin	Species identification and database development	Online personal interview
Thorsten Hinrichs	Federal Ministry of Food and Agriculture European and International Forest Policy, Germany	European and International Forest Policy director	Forest policy and legality verification	Written interview
Carl Guenther Jastram	Enno Roggemann GmbH & Co.KG, Bremen, Germany	Director	Timber trade	Email correspondence
Mark Sanderson	The Forest Trust, United Kingdom	Communications Manager	Forest Legality	Email Correspondence
Phil Guillery	Forest Stewardship Council, Bonn, Germany	Systems Integrity Director	Timber supply chain	Online personal interview

Marion Karrman	Forest Stewardship Council, Bonn, Germany	Monitoring & Evaluation Program Manager	Timber supply chain	Written interview
Amos Bien	ASI-Accreditation Services International GmbH	FSC Auditor	Certification Audit	Email correspondence
Case of Costa Rica				
Miguel Araya	SINAC (Sistema Nacional de Areas de Conservacion)	Forest engineer	Natural resource management	Personal interview
German Rodriguez Coffre	SINAC (Sistema Nacional de Areas de Conservacion)	Coordinator in Forest Management and Use	Forest conservation, timber legality	Personal interview
Axel Chavarria	ONF (Oficina Nacional Forestal)	Manager	Timber market statistics	Personal Interview
Alfonso Barrantes Rodriguez	ONF (Oficina Nacional Forestal)	Executive Director	Timber market trends and statistics	Personal Interview
Sebastian Ugalde Alfaro	ONF (Oficina Nacional Forestal)	Marketing and Commerce Manager	Timber market trends and statistics	Personal Interview
Pedro Gonzalez Chaverri	FUNDECOR	Sustainable Development Manager		Personal Interview
Carlos Porras Salazar	FUNDECOR	Technical Coordinator of the Sustainable Development Management	Timber supply chain management	Personal Interview
Warner Porras Sanchez	SINAC (Sistema Nacional de Areas de Conservacion)	Forestry Unit Manager, Sub-Regional Office Sarapiqui	Timber legality verification	Personal Interview
Guillermo A. Navarro	CATIE (Tropical Agricultural Research and Higher Education Center)	Independent consultant in forest governance, economy and management	Forest policy and management	Personal Interview
Carlos Manuel Navarro	International Analog Forestry Network	International Program Coordinator	Forest genetics	Personal Interview

1.4 Limitations and scope

The limitations of this research are important factors contributing to the final result and can be classified in two categories: circumstances and methodology/scope.

The unavoidable circumstances include hidden bias of interviewees, inability to present confidential market information, inability to interview all relevant actors in the field and include all relevant cases. Besides that, as DNA technology is developing with intensive speed, it is impossible to predict the sudden changes in policy making, market demand, and stakeholder acceptance around the issue. Thus, the findings of this research are applicable for a relatively short period of time and the given information needs to be updated before being referred for any kind of policy or business decision making process.

On the other hand, the findings of this research depend strongly on conscious choice of methodology and scope. As this study does not aim to compare existing timber tracking technologies, it is quite possible that important aspects of these technologies or their effect on the market of genetic methods are overseen throughout the research process. Moreover, as the technology and its environment is analysed in modified version of the TIS framework, the results might be different from the one that a full application of the framework would have borne.

The last chapter presents feasibility analysis of the Costa Rican case, which should not be generalized to other countries, when it comes to political will, market opportunities, etc. Moreover, two months period of studying forest management, timber industry and legality verification systems in Costa Rica was a relatively short time to fully understand the dynamics of the whole system in the country. The unavoidable fact that the majority of informants were contacted through FUNDECOR might also add some bias to the research.

1.5 Audience

This thesis is written for the purpose of obtaining a degree in the Erasmus Mundus Master in Environmental Science, Policy and Management (MESPOM); thus the academic board is one of the main audiences kept in mind during the writing process.

The research demonstrates the possibilities of application of modern technologies to combat illegal timber trade which might be of interest for all involved stakeholders. To this end, it aims to reach policy makers, private businesses, timber certification organizations and members of civil society who are concerned about sustainable forest management and assurance of the legality of timber. Moreover, efforts have been made to ensure that the text uses relatively simple and non-academic language in order to allow public in large, concerned about growing rate of deforestation, to be more informed on the efforts of international community and to understand potential of modern timber tracking technologies.

Besides being an important contribution to the overall research, the Costa Rican case study was mainly intended for the kind consideration of the local NGO FUNDECOR, as well as for the Ministry of Environment and Energy (MINAE) of the Republic of Costa Rica.

1.6 Outline

The thesis proceeds in the following structure: Based on existing studies **Chapter 2** discusses the main concepts related to the topic, the efforts of the international community to seize illegal timber trade, the main shortcomings of the system and the level of damage these shortcomings bring. This lays a foundation for analysis of the RQ1a. The question is further analysed in **Chapter 3 Section 3.2.1** which presents the limitations of existing timber legality verification systems revealed in NGO reports.

Chapter 3 addresses RQ1b by presenting the potential of DNA tracking methods according to the TIS framework. It also develops the main conceptual assumptions around RQ1, presenting the areas where genetic methods might be applicable to address previously identified limitations.

Chapter 4 narrows down all previous discussion to the case level by identifying main limitations of timber legality verification system in Costa Rica. **Chapter 5** discusses the potential application of DNA technologies in the country context. It also goes beyond mere theoretical discussion and presents a feasibility analysis of applying DNA technologies in legality schemes in the country (RQ 2) through the PESTLE framework.

Chapter 7 helps to reflect upon the obtained results, research process and used methodology, which is followed by concluding thoughts, references and appendices.

2 Background

2.1 Definitions

Prior to commencing discussion on the topic, this section aims at presenting main concepts and their definitions given by different authors with the aim to give a better understanding of the scope and focus of the study.

Illegal logging and trade. Being one of the main concepts of this research, it is defined in similar ways in different studies. The definitions include the harvest of timber in breach of either international or national laws. For example, the World Bank defines it as the harvest of timber in "violation of relevant national legislation, including ratified international treaties and conventions" (Panjer & Greenberg, 2012). The EU Forest Law Enforcement, Governance and Trade Action Plan (EU FLEGT) states that illegal logging takes place when "timber is harvested in violation of national laws" (FLEGT Facility, 2003).

Most of the definitions differentiate between illegal logging and illegal timber trade. WWF considers illegality in timber sector as timber harvested or traded in violation of relevant national or sub-national laws or where access to forest resources or trade in forest products is authorized through corrupt practices. The International Tropical Timber Organization (ITTO) provides clear definitions both for logging and trade activities. According to ITTO "illegal logging refers to the removal of logs in a manner that is against the provision of relevant laws, while illegal trade is more complex, involving not only forest laws but also laws on corporations, trading, banking, auditing, customs, taxes, etc." (ITTO, 2014a).

The definition should include different elements, namely, illegal harvest, transport, trade, smuggling, etc. For the purpose of this study, the broad definition provided by FLEGT Facility is the one referred most:

> Illegal harvesting may include not only harvesting practices that contravene the regulations, but also using corrupt means to gain harvesting rights, extraction without permission or from protected areas, cutting protected species or extracting of timber in excess of agreed limits. Beyond harvesting, illegal practices may also extend to transport infringements, illegal processing and exporting, non-payment of taxes or charges, and misdeclaration to customs

Supply chain management. "A supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer" (Christopher 1992). The definition of the management of this network given by Mentzer et al., (2001) is the one chosen for the purpose of this study and applied for the case of timber supply chain management:

> Supply chain management is the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long term performance of the individual companies and the supply chain as a whole.

Chain of Custody (CoC). CoC refers to the chronological documentation through the value chain, from the forest to the consumer, including all stages of processing, transformation, manufacturing and distribution (Forest Legality Alliance, 2015). In the forestry sector, it is aimed to ensure that all relevant standards have been applied in all stages of the supply chain which can be traced back based on previously collected information and passed all the way from producer to the last consumer. CoC certification is employed by timber certification organizations such as FSC or PEFC.

Due Diligence System. Under the EU Timber Regulation (2013) 'due diligence' is explained as the notion operators undertake so as to minimize the risk of placing illegally harvested timber, or timber products containing illegally harvested timber, on the EU market. It includes three elements: information (to state legality of the timber), risk assessment and risk management. "Due Care system" required by US Lacey Act (2008) has a similar meaning.

The rest of the main concepts are explained throughout the research work in relevant chapters.

2.2 Governance of Commons

This section will try to shed light on existing literature on forest governance and timber legality systems. The identified limitations of current forest governance regimes will lay the basis for the findings in the next chapter and the gaps in current studies will serve as a justification for the current research.

Discussion on effective forest governance arises from long the discussed classic debate on governance of commons. Being a common pool resource, global forests are of great importance for humanity and wildlife. As it is the case with other natural resources, the use of forests involves the "tragedy of commons" where individual and direct profits are often prioritized over common and long-term benefits (Hardin, 1968). This is the simplistic reason to explain a great tendency to deplete valuable forest resources and make immediate profits by selling them to countries with growing demand for wood.

Governance of commons has always been a topic of discussion on choice of institutions; whether governmental regulation or privatization of common pool resources is an effective way to deal with the problem still remains an area of discussion. In classical discussion over institutional approaches, Ophuls (1973) argues that the tragedy of commons necessitates the rule of government acting in best public interest. Heilbroner (1974) goes further in claiming that "iron or military governments" are those that can control ecological problems. However, those who are critical about regulation of common resources by central authority claim that this approach might lead to inefficient results, as it falsely assumes that the authority holds accurate information, possesses perfect monitoring capabilities and incurs zero costs of transaction and enforcement (Simmons et al.,1996). Smith (1981) claims that "the only way to avoid the tragedy of commons in natural resources and wildlife is…creating a system of private property rights". In this way, individuals would be directly interested in preservation and rational use of resources allocated to them. However, establishing private property rights over common resources might not work in all diverse situations. As it is also argued by Clark, creating individual property rights, for example for marine fishery resources is not feasible (1980).

Recently the discussion was developed further by authors who believe in self-organization of communities as an optimal way of managing common pool resources. Community management of resources is favoured mostly because of shared responsibility among members and preservation of indigenous knowledge (Oba et al., 2000; Leach et al., 1997). Ostrom (1990) argues that governmental regulation is not an optimal solution due to lack of adequate information and transaction costs. She further claims that loss of ownership by community and rapid commercialization of forest products are the main reasons of global forest degradation (1999). Thus, communities can self-organize in an effective manner and sustain their arrangements for a long time, given that participants have capacity to communicate with each other, understand the future challenges and are not restricted by external institutional arrangements commanding them what to do.

In Ostrom's article from 2005 she also argues that single-level governance is not enough to deal with the sustainable use of natural resources. Thus, multilevel and adaptive governance is necessary. Ostrom and those who think in line with her have established the so called "new institutionalism" where the terms "government" and "governance" are strongly differentiated. The governance of natural resources does not necessarily require central authority and it can take the form of self-governance (Rosenau et.al., 1992; Acheson, 2003; Dolsak and Ostrom, 2003).

2.3 Forest governance

A similar discussion over the choice of institutions has also been held around global forest management for decades. Throughout the time some ways of forest governance have prevailed, bringing new focus points and governance mechanisms. Figure 4 lists the main types of forest governance mentioned in the literature and discussed below.

Figure 4. Forest governance regimes

International

Starting from the 1980s, several international initiatives have led to the establishment of international forest governance in the context of continuous failures of individual national governments to combat illegal wood trade and to ensure sustainable use of global forests, (Humphreys, 2006).

In 1975 The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) entered into force to ensure that trade of 30,000 species of plants, including endangered tree species is regulated. 180 member countries obliged themselves to protect flora and fauna to avoid the extinction of certain species listed in the Annexes 1, 2 and 3. The enforcement of the regulation at national level, especially identification of species, is mainly done visually based on anatomic features of the species (Michael et al., 2012).

The establishment of International Tropical Timber Organization by UN in 1983 and development of Criteria and Indicators (C&I) aimed to assist national governments with sustainable forest management (SFM) (ITTO, 2006).

The foundation of the Intergovernmental Panel of Forests (IPF) in 1995 and its transformation into the Intergovernmental Forum on Forests (IFF) in 2000 was another initiative at international level. However, all these efforts have not yet led to a legally binding international agreement, mostly due to resistance from developing countries on issues such as "opportunity cost" and sovereignty of decision making. Protests by NGOs, demanding more focus on indigenous people's rights and biodiversity, affected the process of negotiations as well (McDermott, 2012).

The adoption of REDD+ by Cancun agreements in 2010 shifted the main focus of forest governance to carbon units emitted through deforestation and on joint actions to avoid these emissions. It resonated well with previous concerns of developing countries which claimed financial compensation to reimburse their "opportunity costs" of forest conservation and to keep "sovereignty" in decision making. Although there is still big optimism about the impact of REDD+ on deforestation, it is too early to talk about its effectiveness. The initiative has received some criticism from academia, as well as from NGOs. Angelsen (2008) and Kelly (2010) claim that REDD+ can lead to more corruption, as governing bodies in developing countries are not ready to deal with received financial payments effectively; it might favour fast-growing plantations over diverse native forests, as this would be an easier way for developing countries to comply with the agreement and avoid emission of carbon units. McDermott (2012) criticizes REDD+ for its oversimplification of forest issues into carbon units and for creating more obscurity. Humphrey (2008) argues that there is a risk that growing demand for agriculture products will increase the opportunity cost of forest preservation to developing countries. If forest preservation prevails, less areas would be left for agriculture activities, which in turn will increase their prices and make opportunity cost even higher.

Bilateral

Starting from the 1990s, illegal logging, as well as weak forest law enforcement and corruption became the main focus of forestry institutions and governments (McDermott, 2012). Affecting timber market or demand side was and still continues to be considered an effective way of dealing with illegal timber trade. Thus, several initiatives have been launched by developed countries to stop the import of illegally harvested timber. Recognizing their role in global timber markets, the EU and USA were the pioneers to deal with the issue. The EU's Forest Law Enforcement, Governance and Trade (FLEGT) initiative (2003), as well as the EU Timber Regulation (2013), the US Lacey Act (2008) and the Australian Illegal Logging Prohibition Act (2012) are the most acknowledged efforts to seize import of illegal timber into national markets (Gan et.al., 2013).

These efforts mainly concentrate on establishing a new policy instrument called "legality verification system", where joint efforts of producer and importing countries aim at establishing an effective bilateral system which eliminates the illegally harvested timber from all supply chains of wood coming from a particular country. Voluntary Partnership Agreements (VPAs) within FLEGT serve as excellent example for this. Since the time of its launch, only six individual VPAs have been signed between the EU and countries such as Cameroon, the Central African Republic, Ghana, Indonesia and Liberia, Republic of Congo (EU FLEGT Facility, 2015) and nine more countries are in the process of negotiation. Although on voluntary basis, once they are signed these VPAs become important part of national legislation. The mentioned six countries together with the EU are currently developing their system of national control, which will result in issuing VPA legality licences for wood originating from these countries. Overall, VPAs have following components: agreement on a legality standard, establishing a chain of custody, implementing a verification system, establishing the license issuing authority in the partner country, and independent monitoring (EU FLEGT Facility, 2015). According to Cashore & Stone (2012) legality verification systems have similarities with national efforts mentioned previously, in a way that they help to improve national regulations and governance as a way to cut illegally harvested timber from supply chains. VPAs are also similar to certification schemes when it comes to issuing licenses for wood which will be recognized in the market as legal. However, unlike certification schemes these licences do not aim to obtain premium prices in the market.

Although implemented with recognized success, these initiatives are not without criticism. Legislations in the USA, Australia, etc. are criticized on the basis of not directly dealing with core reasons of unsustainability and illegality in the exporting countries and just sufficing with banning their import. For example, when the USA tries to stop the import of illegal timber to its markets it can still find its way into other big markets through China or be used in the internal markets of timber producing countries (Sills, 2008). Another criticism is that legality verification systems have narrowed down the focus from the complex environmental and social issues (sustainability) to just legality verification, thus might create a risk of a "race to the bottom" concerning conservation laws in the exporting countries (Cashore & Stone, 2012).

National

Domestic governance of forests, especially in developing countries, have been a subject of criticism on the basis of weak enforcement of robust regulations, lack of coordination, lack of resources of enforcement, competing priorities, violation of indigenous people's rights, as well as for very low wages of foresters leading to corruption and illegal access of outsiders/free riders to forest resources (Contreras-Hermosilla, 2001; Panjer & Greenberg, 2012).

In their four yearlong research, concentrated on countries such as Brazil, Mexico, Indonesia and Philippines, Akella & Cannon (2004) conclude that:

> Enforcement of natural resource and biodiversity laws and regulations is abysmal in these biodiversity-rich countries. The existing enforcement regimes in the countries we studied are weak, and not one of them provides an adequate disincentive to offset the incentives that are driving illegal environmental activities.

A study by the WWF (2005) on the case of Indonesia concludes that most illegal logging cases brought to trial in this country are dismissed because of lack of evidence , poor management, or lack of knowledge by judges, prosecutors and the police on the issue.

Among others corruption in different levels of domestic forest governance is considered the most prevalent problem. Linkage between large logging companies and local elites, as well as little surveillance on local forestry officers and their low wage are considered the most important factors leading to corruption in forestry sector (Global Witness, 2007; CIP & EIA, 2005)

In view of these challenges, besides banning the import of illegal timber, improvement of domestic forest governance in timber producing countries has become one of the major aims of the recent regulations of EU, the US and Australia. Through these policy tools the major focus has shifted from challenging or condemning sovereignty/ domestic policy development to its strengthening (Thang, 2008; Cashore & Stone, 2012).

Community

In the context of forest governance decentralization, community control and management of forests recently has gained greater support for their emphasis on sustainability and shared benefits. Danielsen et al., (2014) stress the role of locally based natural resource monitoring in decision making across developing countries. Jack et al. (2008) support community management of forests and conclude that Payment for Ecosystem Services (PES) serves as an effective method for incentivizing it. In the example of ribereños in Peruvian Amazonia, Halme & Bodmer (2007) claim that local ecological knowledge of the community can assist biodiversity inventories and wildlife management in greater scale. Agrawal et al. (2008) consider empowering community management as one of the necessary tools to address challenges of the forest governance in the near future. However, community management has also been criticized for its limited focus, failure to identify and agree on priorities, capture of benefits by small groups of people, inability to solve intercommunal conflicts, etc. (Roe et al., 2009)

Third party forest certification

Rudel (2005) and Geist & Lambin (2002) argue that unlike the deforestation of 1960's -1980's which was mainly subsistence-driven, the deforestation of today especially in tropical countries is industrial-driven. Thus affecting the way industries are doing business can be considered a much more effective solution to global deforestation.

To this end, since 1990's NGO's and industries in the sphere of forest management and sustainability have launched multi-stakeholder initiatives (MSI). According to Visseren-Hamakers & Glasbergen (2007), the ineffectiveness of public governance caused private initiatives to fill the gap and challenge existing practices through four main institutional forms: 1) Business initiatives; 2) Civil society initiatives; 3) Private inter-sectoral partnerships (strategic alliances between civil society and business); 4) Public–private inter-sectoral partnerships (strategic alliances between governments and business and/or civil society). Certification schemes of sustainable forest products have mainly evolved as the result of NGO-business and public-private partnership. The main aim of these schemes is to develop standards for sustainable forest management, through principles, criteria and indicators. Among all, Forest Stewardship Council (FSC), the Programme for the Endorsement of Forest Certification Schemes (PEFC), the Sustainable Forestry Initiative (SFI), the Canadian Standards Association (CSA) and the Malaysian Timber Certification Council (MTCC) are the ones largely referred in literature and used by businesses. Certification schemes in general have become successful, as the number of certified forest areas increases year by year and certification has translated into a "license to operate" for the timber industries in most countries (Ozinga, 2004; Visseren-Hamakers & Glasbergen, 2007). According to latest statistics on May 2014, industrial roundwood production from certified forests reached 524 million m^3 in April 2014 which makes about 30% of global industrial roundwood production (UNECE & FAO, 2014).

Established in 1993 the FSC, unlike other certification schemes, sets performance based standards; it requires effective, specifically described and verifiable measures to ensure sustainable forest management (FSC, 2015). FSC is the most popular certification scheme because it does not allow any stakeholder groups, especially industries, to influence its standard making and monitoring processes. Having three pillars of sustainability as its core focus, FSC has been supported for a long time to achieve concrete actions regarding forest policy and management (Nebel et al., 2005). FSC is often referred in the literature as exemplary transnational non-governmental regulatory scheme and multi-stakeholder governance forum (Cashore et al. 2004; Gulbrandsen 2008).

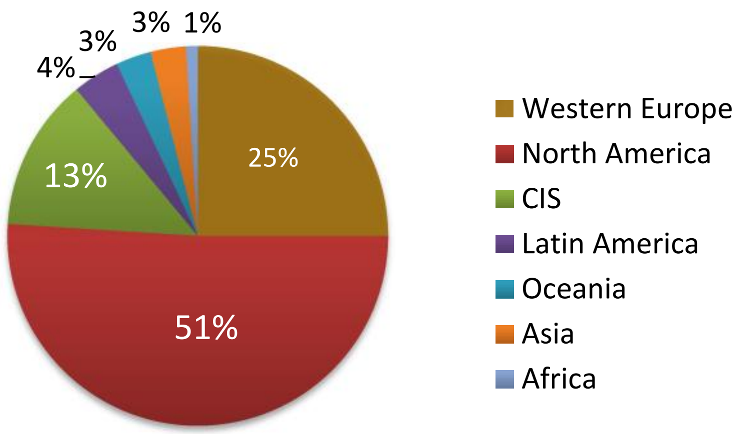

Figure 5. Regional share of total certified forest area (FSC, PEFC)

Source: UNECE/FAO 2014

Bass and Simula (1999) analyse certification schemes based on their effectiveness, efficiency, equity and credibility. The certification can be considered effective if larger areas are protected. However, certifiers have been criticized for focusing on logging activities within the concession area ignoring leakage effect - continuation of illegal and unsustainable logging somewhere else (Greenpeace, 2005; Hance, 2008). Besides that, they are also criticized for not living up to promise of saving global tropical forests, as around 80% of FSC certified forests are located in the north (Pattberg 2005; Nebel 2005)(See Figure 5). Forest certifications are also criticized for less emphasis on biodiversity and too much emphasis on timber trade. Based on FSC statistics, 40% of the total certified area is plantations, not natural forests (2014). Given the fact that natural forests host richer biodiversity than tree plantations, certified forests do not necessarily guarantee higher biodiversity.

Efficiency of certifications (i.e. FSC) is criticized less, as the costs of certification are usually paid off through premium prices. However, recent studies show that the link between customers' willingness to pay for certified wood and its actual sales is not that strong, as it is the case with any kind of labelled product (Schwarzbauer and Rametsteiner, 2001)

When it comes to issues of equity, Bennet (2001) and Ghaozul (2001) are concerned over the ability of best performers to get certified by leaving out small and local forest operators and making it even more difficult for them to access the markets. Bass et al.(2001) argue that concentration of certified operators in the Western world, erodes the chances of developing and tropical forest owners to extract the benefits of being certified.

Credibility involves reliability and acceptance to stakeholders, without any conflicts of interest. This is the aspect that FSC is mostly criticized for. Although for years these certification schemes were viewed as trustful verifiers of legal and sustainable timber, recent reports of NGOs revealed some substantial shortcomings in the way certification work is managed. Greenpeace (2015) has published series of reports where it revealed several loopholes in interpretation of FSC standards by a growing number of certified members with controversial forest management operations. In 2006, a group of activists as well as supporters and members concerned about constant cases undermining FSC's credibility established FSC-Watch. It is operated in form of a website filled with reports or news on errors of FSC management and certification processes. In recent years scandals about FSC certification system found its way to mainstream media as well (Wright and Carlton, 2007; Hance 2008; Lee 2009; Bounds 2009; Poynton, 2013). In most of the cases the root cause of the problem is linked to three systematic failures: credibility of certification bodies accredited by FSC, the complaint mechanism and "mixed" or "controlled wood" label (FERN, 2008; Schepers, 2010; FSC-Watch, 2015).

The quality of certificates issued by FSC accredited bodies is claimed to vary largely. This is linked to growing number of certified timber companies, as well as to the system that makes certifying bodies to be paid by those who want to get certified. This clearly shows the conflict of interest and undermines the confidence in their auditing techniques; more certification translates into more income and being ahead of competitors in terms of certified forest area, which in turn undermines the strictness of the standards and policy (Hance 2007; Poynton, 2013).

"Mixed wood"- the product that is only partly derived from sustainable sources is one of the issues that certifiers have been criticized for (Greenpeace, 2005; Wright & Carlton, 2007). According to most of the critics wood from mixed sources has become the major tactic of smuggling unsustainable and uncontrolled wood into the FSC system (FERN, 2008; Greenpeace 2015; Hance, 2008). "Mixed wood" also accounts for sudden increase in the number of certified businesses in recent years, as it has relatively lax standards (Poynton, 2013).

However, FSC is not the only organization that receives criticism. In response to growing influence of FSC, industry associations have formed Programme for the Endorsement of Forest Certification Schemes (PEFC) which nowadays became an umbrella organization that accredits national certification schemes in different countries (PEFC, 2015). PEFC standards are generally regarded as much more loose, mainly because it is a standard developed by industry itself (Hance, 2007).

In general, the whole third party certification mechanism although welcomed as multi-stakeholder dialog and governance at first, is nowadays criticized for their constant failures. Cashore (2002) criticizes certification processes for being highly politicized. The competition among different initiatives and their standards has led to repetition of efforts and inefficient allocation of global resources; certification schemes have become a battlefield over influence between business and NGOs. McDermott (2012) argues that in the context of having China as a melting pot for most of the traded timber worldwide, having CoC documentation of certifiers still cannot guarantee the legality of the end product. In most of the cases timber businesses source from different subcontracters, the activities of which is very difficult to monitor on a regular basis. Thus, CoC documentation just increases the global paper trail attached to each traded timber (McDermott, 2012). In her 2012(a) article in the example of BC, Canada McDermott analyses how the high number of formal requirements and documentation has led to erosion of trust between stakeholders and imposed the power relations and supervision, which in turn led to higher costs, mistrust and diversion of shared values and commitment to good forestry.

Figure 6. Forest governance regimes and their limitations

2.4 Enhancing existing systems

Literature analysis has revealed that every initiative in an attempt to save global forests and seize illegal timber has received a plethora of criticism (summarized in Figure 6). Thus, it is very challenging to identify single the most effective forest governance regime. Besides, none of these regimes exist in a vacuum and the success of one largely depends on cross enhancement and support by others. Bearing this in mind, recently there have been made several efforts in the direction of improving the existing regimes; this varies from deep structural changes in the system to new technological applications for better monitoring and control. The application of modern technologies such as satellite images, QR-codes, infrared lights, stable isotope analysis, etc. has become recent tendency in this context (ITTO, 2012; WWF Germany, 2014). These methods are believed to enhance existing systems and bring back stakeholder acceptance and legitimacy.

Around a decade ago, news and reports of laboratory researches done in different institutes brought up the idea of DNA tracking for timber as a possible application to verify its legality (Nielsen & Kjaer 2008; Asif & Cannon, 2005; Rachmayanti et.al., 2006). Depending on the purpose of the technology application, DNA technologies can be used to prove that timber comes from the designated concession, by taking samples of timber to compare them against the remaining trunks in logged area, or to avoid the trade of endangered species by comparing the samples against a list of endangered species under CITES. It can also help to verify or disprove the claimed country of origin of the timber. Unlike documentations that currently attached to verification mechanisms, the DNA of a tree is very difficult to falsify (Henley, 2013). Moreover, it is even possible to retrieve DNA of already processed wood, regardless of the time period between logging and its processing (Liepelt et al., 2006)

DNA markers might not only be applied in current certification schemes, but for the purpose of fostering Due Diligence systems or Due Care systems which are required from operators by EU, US and Australian legislations. As a practical tool, it has a potential to substantially decrease the costs and efforts of maintaining such systems or obtaining additional certification to prove the origin of the timber (Henley, 2013; Lowe and Cross, 2012).

Since the beginning of the testing period as a standalone method, genetic timber tracking was classified as the most promising when it comes to investigating wood theft or timber smuggling (Dykstra et al. 2003). Using DNA can help to control the chain of custody of timber companies, as well as help governments in their combat against import or export of illegal timber (The University of Adelaide, 2014).

Despite being a very useful tool, this mechanism has not been adopted by certification companies and governments on a large scale and still continues to be implemented at niche level and for certain species. The application of the technology requires wide scale laboratory work, harmonization and standardization of operations, stakeholder collaboration and significant finances (Fogarty, 2012). A main drawback of the technology is its cost of application. However, experts believe that the cost of operations will fall per species of tree, if the necessary technologies are developed, if operations are realized on a large scale and a continuous basis, and if the reference database is created for main traded species (Nielsen & Kjaer, 2008).

Despite of the wide range of possibilities that DNA fingerprinting for timber offers, no consistent research has been done to match them with the problems related to existing systems. There is very limited information available on how this technology can be used in routine basis on a large scale in the Chain of Custody of certification bodies or private businesses. Thus, the potential of DNA markers will be further explored in proceeding chapters with the aim to fill that gap.

3 Genetic timber tracking methods

3.1 Overview of timber tracking technologies

Due to the identified problems related to forest governance and the traditional paper documentation accompanying timber flow, timber-tracking technologies gained wider usage in recent years. Generally tracking technologies involve recording the flow of wood throughout the supply chain using technology at different levels (ITTO, 2012). The range of techniques varies from very simple to very complicated laboratory works. An ITTO publication (2012) provides a very useful summary of each method. The simplest tracking method is the "mass balance" method, where inputs and outputs of batches of wood are recorded. The next level tracking method is called physical product identification method, where individual wood is traced, but usually only between forest concessions and sawmill - in the first phase of supply chain. This method involves different varieties such as paint markings[8]; plastic tags[9]; barcoding[10]; radio frequency identification (RFID)[11] (ITTO, 2012). Although widely used, physical product identification tools can be easily detached from logs or they show too much dependence on an internet connection in place. WWF Germany (2014) also differentiates microscopic identification, NIR (Near Infrared), remote sensing and paper fibre analysis methods, which have the potential to be employed for different purposes such as species identification and geographic origin, but are still in the process of verification as standalone methods.

The next level of timber tracking technologies is a suite of chemical identification methods which include isotopic and DNA sampling. Isotopic analysis has been largely used in agriculture to identify the geographic origin of products (WWF Germany, 2014). Recently, it has been used in forestry as well. Isotopes are found in the soil and are specific to each region. By comparing the isotopes taken from a region and from timber, its origin can be identified with a certain precision. However, this requires prior registration of isotopes of specific regions (Siedel et. al., 2012). The next section looks into another chemical identification method – DNA tracking – in more detail.

3.2 What is DNA timber tracking?

DNA, or deoxyribonucleic acid, is the hereditary material within all living organisms. DNA analysis is traditionally used for parentage testing or criminal cases. The technique was developed in 1984 by British geneticist Alec Jeffreys and it involves developing highly variable repetitive sequences (unique to each individual) called variable number tandem

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[8] the colour paint indicating a certain serial number is used to differentiate the wood;

[9] each tag is accompanied with a unique identification number and fixed on timber;

[10] the fixed barcodes are scanned and the information directly sent to a database;

[11] unique ID number is scanned and it is wirelessly transferred to a database together with other data related to the product

repeats (VNTRs), as well as short tandem repeats (STRs) (Encyclopedia Britannica, 2014). The usual procedure of DNA testing follows the steps of extraction the DNA sample, its purification and amplification through Polymerase Chain Reaction (PCR), cutting the DNA with the help of restriction enzymes at length of VNTRs and separation of DNA fragments through a process called Gel Electrophoresis. When the end product is exposed to X-ray film, then certain patterns of DNA bounding, called DNA fingerprinting can be clearly observed (Encyclopedia Britannica, 2014). Based on these patterns DNA samples from two or more individuals can be compared to each other to confirm or refute the linkage among them.

Having developed into one of the main forensic methods, genetic identification has been previously used in different cases involving illegal trade of ivory (Wasser et al., 2007), fish (Magnussen et al. 2007), etc. New developments in the technology and its successful application for plant species allow its use for cases of illegal timber trade as well. However, extraction of DNA from wood and its purification is a relatively complicated process. It is easier to obtain and identify it from a living tree or leaves; however, it becomes more complicated to extract it from dead cells of heartwood, the exact part of tree that enters into markets (Personal Communication, Brend Degen, 03-02-2015). Despite these complications, recent developments in technology allow DNA extraction from dead heartwood with a certain precision (Deguilloux et al., 2002). Overall, in the last 15 years there have been several successful studies on extracting DNA from processed and degraded wood (Rachmayanti et al., 2006; Asif and Cannon 2007). It has even been possible to extract DNA from a five hundred year old wooden bed and prove the species of origin as European White Oak (Degen, 2014; Planetopia, 2013). Figure 7 shows the increasing difficulty in the extraction of DNA from processed wood products.

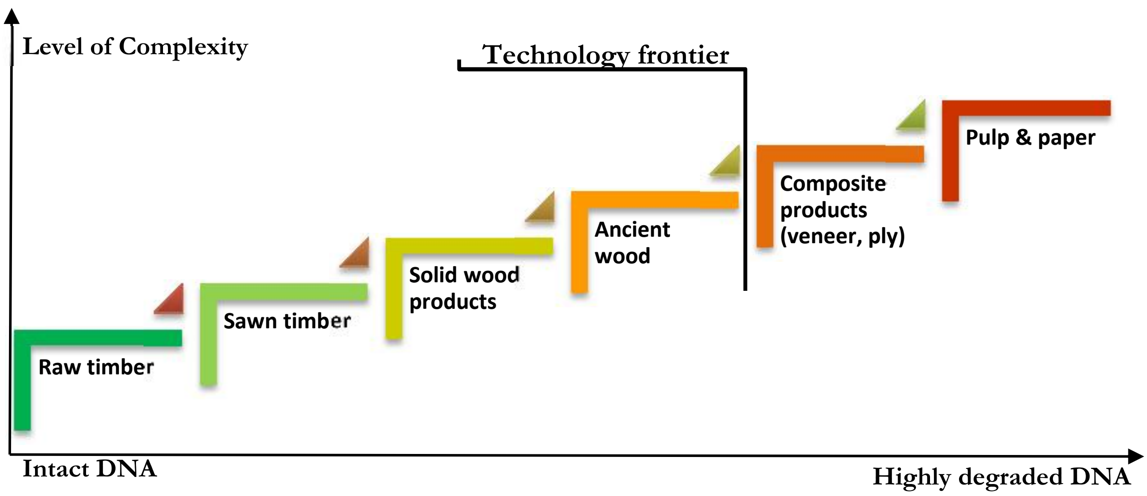

Figure 7. DNA extraction from wood. Current boundaries of possibility

Source: Lowe,2012

3.2.1 Scales of application

The application of DNA technologies in forest genetics is currently done at three main levels (Degen, 2014):

1) Species identity;

2) Geographic origin of wood;

3) Timber from declared individual tree.

These three levels of application are performed respectively through the usage of three different DNA technologies, namely DNA barcoding, population genetics and DNA fingerprinting. Despite addressing different issues these techniques are not mutually exclusive and developments in one method affect the others as well (Double Helix, 2011). Figure 8 gives a summary of each method and the areas of their application.

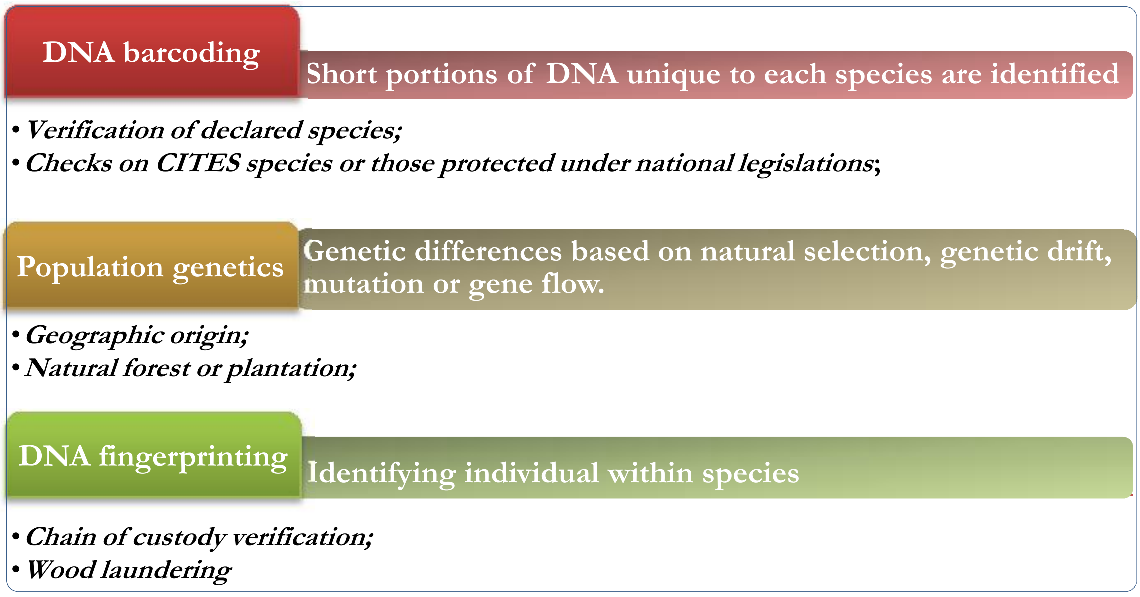

Figure 8. DNA methods and their application.

Source: Adapted from Double Helix, 2011

DNA barcoding allows the identification of species at high certainty. By identifying the DNA structure of each species and subspecies it is possible to create a database of wood and reveal the fraudulent cases, as it is usually difficult to differentiate wood from related species with the naked eye once they are converted into timber (Personal Communication, Marius R.M. Ekué, 20-03-2015). Among all, chloroplast (cp) DNA is considered the most successful source for this kind of genetic identification (Michael et al. 2012) where each species reveals distinct parts of DNA which can be codified as the unique barcode. It is considered to be a useful tool for controlling trade of CITES species. These species are currently exploited in 2 ways: the listed species are exploited and then declared as their close relative species which are not listed in CITES Annexes; or the same species is extracted from a region where it is endangered and then smuggled into another region where it is not, to give a false country of origin. DNA tests can help the controlling authorities to address both these issues by simply comparing sample DNA with an already developed database for each species (See Box 1 for Case example).

Box 1. The case of Central and Western Africa

In April 2013 Global Witness published their report on illegal logging and trade practices in four of the tropical forest countries in Central and Western Africa: Democratic Republic of Congo (DRC), Cameroon, Ghana and Liberia. The NGO revealed that misuse of small title permits has become a major threat to precious forests in these countries that are either part of VPAs with the EU or have commenced the process of negotiation. Artisanal logging permits in DRC, Private Use Permits in Liberia, Salvage Permits in Ghana, Small Titles in Cameroon are described as shadow permits and claimed to be mechanisms used by big logging companies to disguise their logging activities and continue business as usual while facing restrictions and regulations on large-scale operations somewhere else due to EUTR or VPAs. The ways these small permits are abused vary from country to country. For example, according to national law in Cameron small titles are those originally intended to benefit small scale loggers to collect abandoned timber from forests. Instead, due to corruption and weak governance these permits are granted to supporters of the political elite. Then they are further distributed to foreign logging companies (often from China) to extract timber with the same rate as large scale operation does. Or, for example, in Ghana Salvage Permits are designed to acquire already cut timber from the land allocated to development projects. According to investigation, these "development projects" are used to extract wood from deep inside the forests. According to the report, these permits are used mainly to extract precious species such as Wenge *(Millettia laurentii)* in DRC (endangered according to IUCN Red List), Rosewood *(Dalbergia nigra)* in Ghana (Appendix I of CITES), Iroko (*Milicia excelsa)* in Cameroon (Vulnerable according to IUCN Red List), most of them being exported to China, where it is processed and sold to US or EU markets. The organization strongly urges inclusion of the regulation of small and communal permits, as well as large scale operations in VPA negotiations between EU and these countries (Global Witness, 2013).

The core issue

Misuse of legal small permits to extract wood on a large scale; Extraction of valuable and endangered species

Hypothetical application of DNA technologies

Use of DNA barcoding to identify the species, as well as their origin through population genetics at the point of import into EU or the US

Population genetics allows identifying spatial patterns in genetics of tree population which are caused by glacial times, recolonization, seed dispersal due to natural barriers, etc. (Double Helix, 2011). A genetic pattern can be developed based on prior thorough sampling from the region and its precision depends on the sampling proximity. By comparing the given sample with the database it is possible to identify the region/country of origin as well as help to differentiate between forest and plantation timber. This in turn helps to verify or refute the declared origin of the timber (Double Helix, 2011) (See Box 2 for Case example).

Box 2. The case of Russia

In 2013, the Environmental Investigation Agency (EIA) published a report showing how the precious temperate forests of the Far East region of Russia, which at the same time is home to the endangered Siberian tigers, are being logged illegally and at unprecedented scale. The destruction of these forests has great impact on the biodiversity of the region as well as on the life of local indigenous people (Udege, Nanai and Evenks). The area can be compared to the Amazon forests in their importance and role as a carbon sink since deforestation in this area causes permafrost forests to disappear and releases methane to the atmosphere. Multi-year undercover investigation by an NGO has revealed the main technique used by illegal loggers: in most of the cases local suppliers to Chinese logging companies use "sanitary logging" as an excuse to get an access to the forests. Instead of cutting allocated ones, they log the trees with better quality and of rare species which will bring more money in the market. After logging, they use the stamp for sanitary logging to take out the logs from the forests without any checks. Corruption and weak governance in place contributes to enable these fraudulent actions. Chinese ports bordering Russia function as a black box for this illegal timber imported mostly from the Khabarovsk Province of East Russia. Chinese companies (such as Suifenhe Xingjia Group (Xingjia)) link the European and US citizens to the destruction of these valuable forests, by claiming the origin of wood as China or America. According to estimations by EIA, the timber import from these areas of Russia equals to around 20% of timber exports from China. Taking into account the role of China as a main timber exporting country to EU and US, the scale of the problem is quite worrying. According to investigations, the primary manufacturer of U.S. flooring retailer Lumber Liquidators' Virginia Millworks has been the major client of Xingjia Group (EIA, 2013). At the time of writing this thesis, Lumber Liquidators are facing criminal charges under the US Lacey Act.

The core issue

Using sanitary logging permits and stamps to log precious wood; declaring a false country of origin

Hypothetical application of DNA technologies

Using population genetics to verify the origin of wood exported from China and stop destruction of valuable Russian forests

The third method, ***DNA fingerprinting*** presents a way to investigate whether the timber comes from a declared individual tree of a certain forest concession (Personal Communication, Bernd Degen, 03-02-2015). Even among the same species, genomes of trees have parts called microsatellites that are different in each individual tree (Scheliha & Zahnen, 2011). This allows linking each individual tree to its stump by randomly taking samples from trees prior to their felling and check the integrity of supply chain at any point till last consumer (See Box 3 for Case example).

The boxes following each method description showcases the hypothetical considerations where DNA technologies can be extremely helpful. The arguments are developed based on obtained knowledge through literature review and expert interviews.

Box 3. The case of Brazil

A blog post by Greenpeace activists dated back to October, 2014 (about their investigation throughout August-September of that year) claims that with the help of GPS locators activists could trace a timber industry owning a legal forest concession in the state of Para and prove that it has been engaged in illegal harvesting of timber from surrounding areas overnight, bringing that timber to a sawmill and using previously obtained documents to sell it under legal name to unaware customers. Based on satellite images the NGO claims that the timber exporter called "Rainbow Trading" is engaged in illegal logging from surrounding areas of its legal and privately owned estates. In fact the areas that the company suppliers harvest their timber are publicly owned state forests in Para. According to Greenpeace, the scam of "obtaining permission to exploit the land that will never be logged" is the main trick to obtain a fake source of origin for illegal timber. Summarized in "The Amazon's Silent Crisis" the investigation shows how the weaknesses of the control system and lack of resources of law enforcement create a basis for fraud and timber laundering. Given that the timber from this state of Brazil is exported mainly to the US and EU, according to new legislations of these countries the importers should have Due Diligence System in place to assess and mitigate the risk before importing timber into markets. However, the businesses in the US, France, Belgium, Spain, etc. continue buying tropical wood from this state without considering the high risk of illegality. Based on official calculation 79% of logged timber in Para is illegal. Referring to this statistics NGO urges the businesses to stop buying from this high risk area or to maintain credible legality verification system besides official documentation (Greenpeace, 2014).

The core issue

Logging activities outside of legal concession and use of fake permits

Hypothetical application of DNA technologies

As an extreme case, DNA fingerprinting for the verification of Chain of Custody integrity by the companies that export timber from Para state

The case studies are the ones reported by different NGOs which serve as example to explain different kinds of limitations of the system. Box 4 follows the same logic and tries to explain how DNA methods can be applied in timber certification processes.

Figure 9 helps to visualize all three methods and better understand their differences. In the first picture, the genetic differences/barcodes of the same species that is different from the rest, in this case of Khaya *(Khaya spp.)* is demonstrated (Degen, 2014). The second picture shows genetic differences of the same species grown in different locations, in this case different populations of Merbau (*Intsia spp.)* in South-East Asia (Double Helix, 2011). The third picture represents how DNA fingerprinting is used to confirm uniformity of the samples taken in different stages of the supply chain and verify that they belong to the same tree (Degen, 2014;)

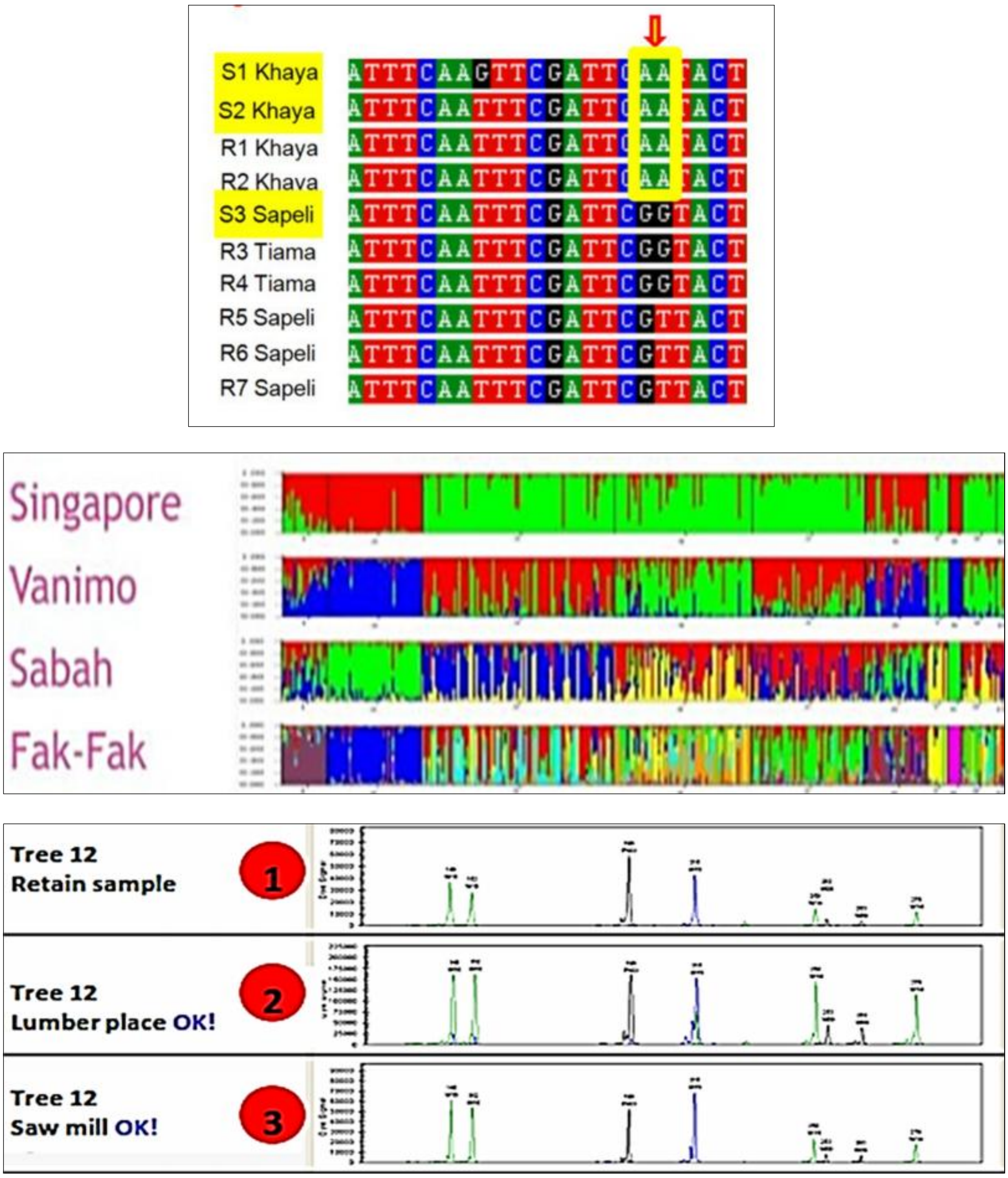

Figure 9. Visualization of DNA barcoding, Population genetics and DNA fingerprinting methods in respective order

Source: Degen, 2014; Double Helix, 2011

Box 4. The case of FSC in Canada

As mentioned previously, "Controlled wood" is the type of FSC classification that is criticized most. "Controlled wood" was originally designed to help businesses seeking FSC certification to be able to mix pure FSC wood with non-certified but strictly controlled one. This in turn would serve as a preparatory and intermediary step to acquire full FSC certification. However, a number of NGOs including Greenpeace have revealed several flaws related to controlled wood operations in countries like Finland, Russia, Canada, etc. A case is recorded in a report dating back to August, 2013 which describes how operations held by Resolute Forest Products (the biggest FSC certificate holder in the world at that time), are threatening the high conservation value areas (HCVs) in Ontario, Canada where the company owns large areas of forests. The old-growth forests in northern Ontario are considered to be habitats of endangered Woodland Caribou (*Rangifer tarandus caribou*). The region also hosts the lands that are in ongoing dispute between indigenous peoples and resource companies. Thus the forests do not fall into the category of low social and ecological risk area required by FSC Controlled Wood standards (FSC, 2006). To this end, the NGO has been urging Resolute to conduct detailed risk assessment for its controlled wood sourcing and calling upon FSC to deal with cases jeopardizing its integrity properly (Greenpeace, 2013a). Quick internet search with the aim of getting more updated information on the issue, as well as personal interview with FSC Systems Integrity Director have confirmed that FSC has revoked its certificate from the company starting from beginning of 2014 due to major inconsistencies (Personal interview, Phil Guillery, 01-05-2015).

The core issue

Contamination of certified wood with uncontrolled wood from high-risk regions

Hypothetical application of DNA technologies

Applying DNA tests during independent audits by certification body to identify the species and origin of suspicious wood within "Controlled wood" scheme.

3.2.2 TIS framework and DNA technologies

After presenting the current developments in DNA timber tracking technologies and identifying the levels and context at which the technology might help with faced limitations of legality systems, this section aims to analyze the current status of the technology and its contextual environment for the purpose of answering the RQ1a. The TIS framework discussed in the methodology section will serve as guidance to this end. As mentioned previously, different authors have made use of the framework at different levels. In this study the description presented in Bergek et al. (2008) is taken as primary reference shown in Figure 10.

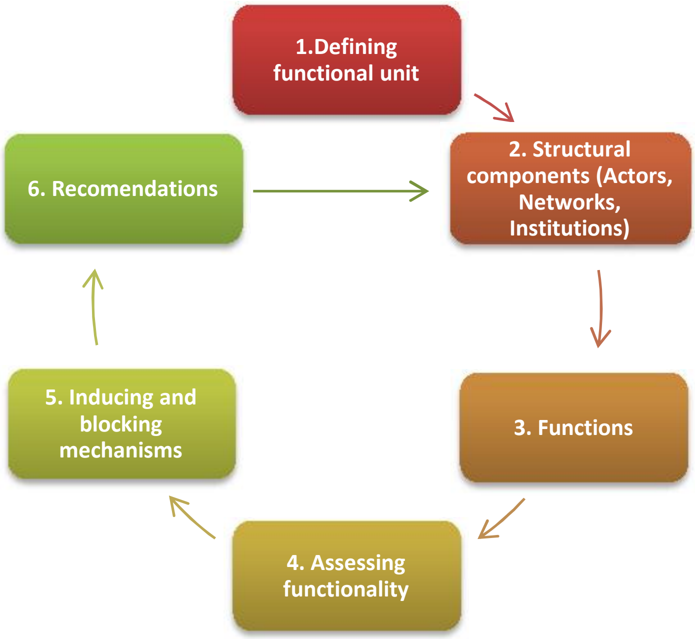

Figure 10. TIS framework and its elements

Source: Bergek et al., 2008

3.2.2.1 Step 1. Functional unit.

According to the framework, the first step is to identify the technological innovations system in focus. The *Functional unit* of the analysis can be either the product/artifact of innovation or the knowledge field. Based on the description of the technology given in the previous section, it is more suitable for the purpose of this research to identify the functional unit as knowledge field or know-how developed though years by different actors and currently revealing itself in terms of genetic timber tracking methods. The *breadth of the knowledge* field is three particular scales described in the previous section, namely DNA barcoding, population genetics and DNA fingerprinting[12]. The application of these methods for the purpose of identifying tree species and their origin is the *range of application* of the innovation.

3.2.2.2 Step 2. Structural components

Structural components can be considered as bones of the innovation system that interact with each other and lead the development of the technology in a certain direction. The framework classifies them as actors, institutions and networks. For the purpose of this

[12] As the technology develops really fast, any newly discovered scales of application should also be included into breadth of the knowledge field.

research, the structural components are identified through bibliometric analysis[13], basic internet search and snowball method during interviews.

A) Main actors - can be grouped into research centers, governments, intergovernmental organizations, NGOs and businesses.

Research centers

Currently, the two main research institutes that deal with DNA extraction and development for timber are the Thünen Institute for Forest Genetics in Germany and The University of Adelaide in Australia.

Thünen Institute for Forest Genetics is part of the Johann Heinrich von Thünen Institute Federal Research Institute for Rural Areas, Forestry and Fisheries in Germany. It is an institute specifically mentioned in the Timber Trade Protection Act (HolzSiG), the German national law on the implemention of EU Timber Regulation for checking the origin of timber in case of uncertainty (BMELV & Thünen Institute, 2013). The institute is operating with close support of the German Ministry of Food and Agrilculture and operates a laboratory where DNA tests are conducted. It is closely engaged in projects on developing competence and establishing similar laboratories in tropical forest countries, especially in Africa[14] (Personal Communication, Brend Degen, 03-02-2015). Just in 2013, 160 wood samples were analyzed in the laboratory of the institute, of which some 10-20% refuted the correctness of the claims (Degen, 2014). Besides national and international authorities, traders and private persons, the institute usually recieves requests from NGOs (up to 50%) to analyze the samples they obtained as the result of "mystery shopping" in major wood retailers around Europe (Degen, 2014).

The University of Adelaide is the next major scientific center where laboratory researches are done and reports published. While Thünen institute is mainly concerned with the legality tests for African and Latin American region, University of Adelaide is dealing with tracking wood from South-East Asia (Personal Communication, Bernd Degen, 03-02-2015). Currently the scientists in University's Australian Centre for Evolutionary Biology and Biodiversity are involved in a project of International Tropical Timber Organization (ITTO) for developing DNA markers for important timber species in Indonesia (The University of Adelaide, 2014).

Besides these two large laboratories there are Forest Genetics Laboratory in the Forest Research Institute in Malaysia[15], as well as an institution in UK called Trace Wildlife Forensic Methods that are dealing with DNA methods for wood species.

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[13] Mainly citation review

[14] Such as the ones at the Forest Research Institute in Ghana for West Africa; at the Institut de Recherche en Ecologie Tropicale in Gabon for Central Africa; and at the Kenya Forestry Research Institute in Nairobi for East Africa (Degen & Bouda, 2015)

[15] In cooperation with Biodiversity International (Personal Communication, Marius R.M. Ekué, 20-03-2015)

International organizations

Since its establishment in 1986, the ITTO has been working in policy making and its implementation in the sphere of conservation and sustainable management, use and trade of forest resources. Application of DNA technologies in forestry has drawn the organization's attention as well. It is currently serving as a funding organization for different projects aiming to establish a unique DNA database for different timber species (for example, Project 620/11 Rev.1 (M)- Development and Implementation of a Species Identification and Timber Tracking System in Africa with DNA Fingerprints and Stable Isotopes) (ITTO, 2014).

The Global Timber Tracking Network (GTTN) was established in 2011 and is coordinated by Bioversity International through the CGIAR Research Program on Forests, Trees and Agroforestry. GTTN plays the role of a forum for facilitating and promoting the integrated use of DNA and stable isotope markers and aims to develop a global database for main commercial timber species to provide tangible proof for species identification and declared origin (GTTN, 2015).

In addition to these organizations, the World Resource Center (WRI), the Forestry Department of UN FAO, the Biodiversity International, etc. are also involved in the issue at different levels. Timber tracking technologies (especially genetic methods) are gaining increasing interest and will be one of the main topics to be discussed in coming XIV World Forestry Congress in Durban (Personal Communication, Jukka Tissari, 10-03-2015)

Non-governmental organizations

The World Wildlife Fund, especially WWF Germany, is the main non-governmental organization showing full support for wide-spread application of DNA and isotope technologies. It has been involved in different projects since 2004 and acted as an organizer of workshops, such as "Genetic and isotopic fingerprinting methods-practical tools to verify the declared origin of wood" which was held in Eschborn, Germany in November, 2010. (Scheliha & Zahnen, 2011).

The Envrionmental Investigation Agency (EIA) is showing its interest in wide application of the technology in the recomendation parts of their reports on illegal logging as a way to maintain credible chain of custody of timber companies (EIA, 2013)[16].

Governments

Since its enforcement in 2013, the EU Timber Regulation has become an important legislation for legality verification of the wood and its products placed in the EU market for the first time. The timber companies are required to maintain risk assessments and mitigation in terms of Due Diligence, which requires additional efforts to be taken along with the usual documentation. This in turn creates a further push for businesses to consider applying DNA technologies in their supply chains (Personal Communication, Darren Thomas, 25-02-2015). Thus, the European Commision plays an important role in dissemination of information about the technology.

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[16] Unfortunately, multiple efforts of contacting the organization with the aim of getting more precise information did not succeed

Being one of the advanced countries in implementation of EUTR, the German government shows great support for the application of technology through the Ministry of Food and Agriculture and by financing different projects and workshops aimed at addressing illegal timber trade in tropical timber countries and developing capacity for DNA testing, especially in Africa. During audit checks on businesses in Germany some samples were taken and sent to Thünen Centre for verifying the species declaration in 2013 and declaration of origin in 2015 (Personal communication, Thorsten Hinrichs, 05-04-2015).

Being very strict in implementation of EUTR, the UK commenced the conduct of regular random checks on businesses. The recent audit conducted by the National Measurement and Regulation Office (NMRO) in February 2015 revealed that 14 major plywood companies (out of 16) have insufficient Due Diligence Systems to meet the standard required by legislation to assess and mitigate the risk on legality of the timber. 13 purchased wood samples were tested through microscopic analysis of which 9 of them did not match their declaration. The report states that during next audits DNA tests will be considered in order to narrow down the results at species level and country of origin (Pillet & Sawyer, 2015).

The US Lacey Act (2008) is the main driver in the US for legality checks of the imported timber. The recent audit and charges against Lumber Liquidators, the major wood flooring company in the US (after the report of the Environmental Investigation Agency) forced the company to opt for DNA testing to manage its forest product supply chain starting from summer 2014 (Lumber Liquidators, 2015).

Besides EU and the US, Australia is the next country with strict regulations on timber legality. The Illegal Logging Prohibition Act which came into force in 2012, forces Australian companies to assess their risks through additional measures such as DNA tracking (Fogarty, 2012).

Certification and accreditation bodies

At the time of writing, just two institutions applying genetic methods in either their accreditation process or certification audits could be identified. The first one is the Accreditation Services International (ASI)[17] which has developed the Traceability and Forensics Procedure since November, 2014. The procedure explains how ASI will conduct inspection and assessments via a review of certification documents and/or a physical analysis of certified product samples through genetic methods (Personal Communication, Amos Bien, 28-04-2015).

The second one is CertiSource, established in 2007. It has become one of the major institutions providing Legality Standard in Indonesia. Double Helix is acting as a certification body against the CertiSource standard and conducts audits through genetic tests for the certified businesses. Some eight mills are certified under CertiSource in Indonesia by Double Helix (CertiSource, 2015).

[17] Being a for profit company ASI is founded by the FSC and nowadays is one of the world's leading accreditation bodies for sustainability standards systems (ASI, 2015)

Businesses

The leading business in the sphere of supply chain management through DNA is DoubleHelixx Tracking Technologies located in Singapore. Established in 2008, it is the only company in the world so far to develop and commercialize DNA tests for wood and license the technique to accredited laboratories globally (Double Helix Tracking Technologies, 2015). The company nowadays offers its services to businesses that wish to apply the technology to verify their supply chain and abide by new regulations. It is also taking active part in different projects together with ITTO, Thünen Institute and other research organizations (Personal Communication, Darren Thomas, 25-02-2015).

Timber importer and wholesaler Enno Roggemann was identified as the major company in Europe applying DNA testing in its legality verification system (Personal Communication, Brend Degen, 02-03-2015). According to its website, Lumber Liquidators in the US has started applying DNA tests starting from summer 2014 (Lumber Liquidators, 2015). Kingfisher, Marks & Spencer and Australian timber wholesaler Simmonds Lumber were either applying it or considering its application as of 2012 (Fogarty, 2012)[18].

B) Networks

As mentioned previously GTTN serves as platform for different actors involved in timber tracking technologies to exchange knowledge and work in different aspects of innovative technology. The genetic timber tracking methods are patented under Double Helix which is leased to other laboratories that have to work under the standards. Thus, there is a strong network among Double Helix and laboratories in Germany and Australia. Besides, the German government and Thünen Institute form another close cooperation and enforce each other's operation. The International Barcode of Life (IBOL) is considered the biggest initiative and network when it comes to genetic identification of living organisms. Within IBOL an ambitious large-scale project called "Tree-BOL" has been commenced with the aim of developing DNA barcodes (identification at species level) for all known 100,000 species of trees around the globe. The participants are working in local and regional teams for the purpose of contributing to the project and existing database (BGCI, 2007)

New timber regulations in the EU, the US, Australia, national legality verification systems formed through VPAs of FLEGT (6 up to now) and other similar initiatives serve as major institutions pushing for the use of technology. Besides, timber procurement policies in the UK, Denmark, Netherlands, Japan, New Zealand, and Germany also urge for thorough legality verification of the timber. Increasing awareness among consumers, as well as pressure from environmental NGOs leads to development of "inofficial" norms for businesses that require robust management of supply chain and risk management on illegal and unsustainable wood.

[18] Email request was sent to mentioned companies with the aim of obtaining updated information which resulted in no response by the time submission date of this thesis work.

3.2.2.3 Step 3-4. Functions and their assessment

The Bergek et al. identify seven main functions on which the technological innovations system need to be analyzed. These include 1) Knowledge development and diffusion; 2) Influence on the direction of research; 3) Entreprenual experimentation; 4) Market formation; 5) Legitimation; 6) Resource mobilization; 7) Developement of positive externalities. Despite being a very important part of the framework, in this research the analysis on Functions of genetic timber technologies (Step 3) and their assessment (Step 4) is skipped due to space constrains, as well as different focus of the study. As different aspects of Functions are mentioned every now and then in the previous and next Steps, avoiding repitition also became one of the reasons.

3.2.2.4 Step 5. Drivers and barriers

Unlike the referred TIS framework by Bergek et al. (2008) which focuses on identifying the inducement and blocking mechanisms of the system to fulfil its functions, this thesis concentrates on drivers and barriers for wide spread application of the technology summarized in Figure 11.

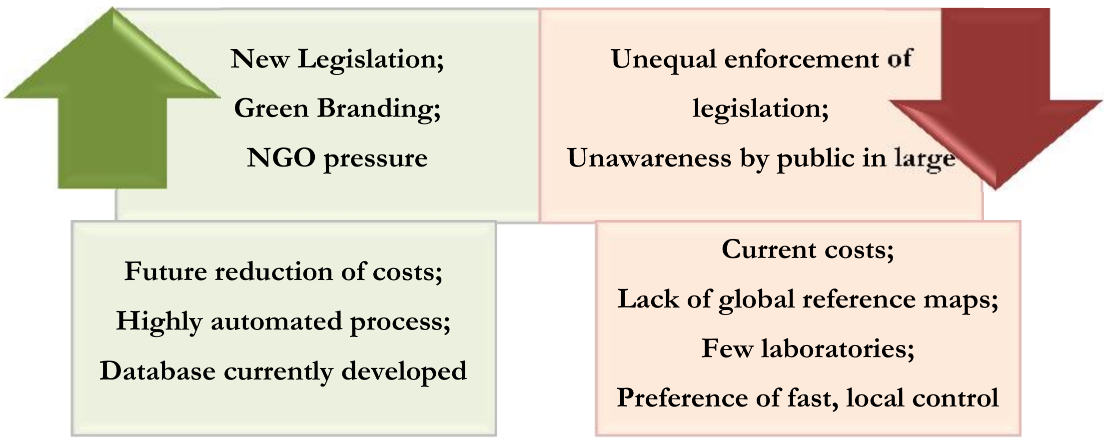

Figure 11. Drivers and barriers of genetic timber tracking technologies

Source: Own elaboration

Drivers

The drivers of wide-spread application of DNA timber tracking technologies can be classified as external and internal.

The above mentioned recent legislations in the US (Lacey Act, 2008), EU (EUTR, 013) and in Australia (Illegal Logging Prohibition Act, 2012) indirectly have become the main drivers for dissemination of the technology and its practical application in timber supply chains (Degen, 2014). As these legislations are relatively new and still in the initial phase of robust implementation the demand for DNA testing is expected to rise. (Personal Communication, Marius R.M. Ekué, 20-03-2015).

Although not yet firmly established, green branding and access to markets through sound DNA checks is considered an important external driver for businesses in EU and the US to apply the technology (Personal Communication, Sebastian Schrader, 20-01-2015).

The increasing number of reports on cases of illegal logging by NGOs, as well as overall pressure from civil society is yet another driving force for timber companies to apply credible verification systems and opt for DNA tracking technologies (Personal Communication, Darren Thomas, 25-02-2015). Besides, implementation of the CITES Convention and bans of imports of wood from certain areas are also major external drivers in this context.

The personal interviews with experts in the field have revealed several internal drivers that make the technology accessible for a wider range of stakeholders. Although implementing DNA tests in the chain of custody is still considered to be costly for businesses, it is believed that these costs will drop based on two factors: time/ technology development and economies of scale. The DNA sequencing process is becoming more and more automated, thus it reduces the costs. The observation by experts has revealed that the price of DNA tests for timber decreased faster in the recent 10 years, than it was the case for human DNA extraction in first 10 years of its development (Personal Communication, Darren Thomas, 25-02-2015). The vision for the next 5-10 years is to have highly automated hand devices for species identification and other DNA tests on spot and fast (Personal Communication, Bernd Degen, 02-03-2015). Moreover, the current projects aimed at developing global reference maps for traded timber species will help to reduce the costs substantially in the future, as nowadays the significant part of the costs of an isolated tests are caused by sampling, field visits, salaries, etc.

Barriers

The main external barrier for the large-scale application of the technology in Europe is considered to be unequal implementation of EUTR in different countries of Europe. While countries like UK, Germany, Netherlands, etc. are very strict in enforcement and audits, timber with dubious legality still finds its way into European markets through countries that are lax in their enforcement efforts (WWF, 2014). Thus, this uneven playing field makes the businesses that wish to apply the technology face competition by cheaper timber and therefore causes them to refrain from adding extra costs to their supply chain.

Although believed to drop in recent future, currently costs of DNA testing are considered to be the major internal barrier that inhibits its dissemination. The cost of a single test is about USD 150-400 (Personal Communication, Darren Thomas, 25-02-2015). Although it makes just 2-5% of overall price of e.g. track loaded with timber, businesses still hesitate to add that cost voluntarily.

Another internal barrier related to the technique is the lack of availability of global reference maps for all major timber species. Up to now, databases have been developed for only 33 timber species globally (Personal Communication, Marius R.M. Ekué, 20-03-2015). While work on this problem is in the progress, it currently creates barriers and dependence.

As mentioned previously, there are only few laboratories in the world that deal with timber DNA extraction. This creates a barrier in two ways: in case of high demand the capacity of these laboratories to deal with requests is unknown.[19] Existence of only few laboratories where tests can be done creates yet another barrier for developing countries that prefer fast and less costly analysis, preferably performed locally.

3.2.2.5 Step 6. Recommendations

The analysis of the last step is given in the concluding chapter of this research work.

[19] Thünen Institute aims to increase its capacity from 5 to 40 DNA extractions per day in recent future (Degen, 2014).

4 The case of Costa Rica. Challenges on timber legality

This chapter aims at presenting overall picture of national timber legality verification of Costa Rica, identifying the causes of illegalities in the timber sector and loopholes in the system, as well as analysing the potential of DNA timber tracking technologies to address these issues. The potential of DNA technologies is further assessed using the PESTLE[20] framework with the aim of providing a feasibility analysis and moving one step further from the hypothetical considerations provided in Chapter 3 for previous cases.

4.1 Country profile

Extending from northwest to southeast between the Atlantic and the Pacific ocean, Costa Rica is the third smallest country in Central America. It neighbours Nicaragua and Panama. Although its area only comprises 51 000 square kilometres, the country hosts around 5% of world biodiversity and 12 life zones (Embassy of Costa Rica, 2015). Having abolished its army in 1949, Costa Rica has been investing in sustainably in health and education. As a result, nowadays it is considered a higher middle income country and one of the most advanced ones in the Latin American community (Central Intelligence Agency (CIA), 2015). The Happy Planet Index has ranked the country number one of all the countries analysed (2015). The country is member of organizations such as FAO (Food and Agriculture Organization) and CITES ,

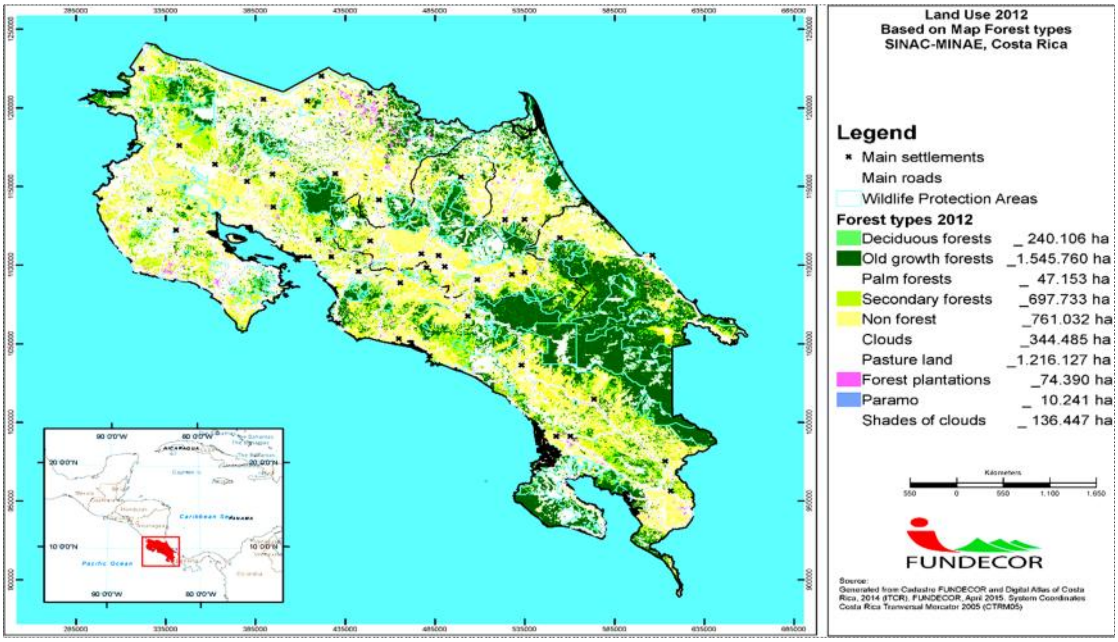

Figure 12. Forest cover of Costa Rica

Source: FUNDECOR

[20] PESTLE- Political, Economic, Social, Technological, Legal, Environmental.

Costa Rica is often considered an ecotourism model, where conservation and economic development goes hand in hand. While the main economic activity is tourism, the country exports gold, different computer parts, electronic microstructures, textiles, medicines, and agricultural products such as bananas, pineapple, coffee, melon, etc. (CIA, 2015).

The country is also the birthplace of the concept and application of Payment for Ecosystem Services (PES). The tax on hydrocarbons partially funds the national system on PES (FINOFIFO, 2015). 25% of country's area is under protection within 20 national parks, 26 protected areas, 9 forest reserves, 8 biological reserves and 7 wildlife sanctuaries (SINAC, 2015). Furthermore, Costa Rica is currently on the way of becoming one of the largest forest carbon buyers in the world and aims to become a carbon-neutral country by 2021 (Embassy of Costa Rica, 2015).

4.2 Timber market of Costa Rica

The forest sector contributes only around 1,2 % to the overall GDP of Costa Rica[21] (Lebedys & Li, 2014). In 2013, around 970 000 m3 wood were harvested nationally, 73,2% of it originated from plantations, 21,9% from pasture lands and 5% from forests. The extracted wood was used mainly for packaging (45.9%), construction (22.5%), furniture (13.6%), exportation in the form of roundwood or processed wood (17.7%) and other uses (0.3%) (Rodríguez & Alfaro, 2014a).

The statistics show that the value of total timber, charcoal and manufactured wood exports of Costa Rica for the year 2013 were USD 66, 45 mln., while imports were USD 76, 43 mln.. When it comes to furniture, the country exported only USD 6.17 mln. worth furniture, while imported USD 22,25 mln.. Thus, the total Costa Rican trade balance for basic wood products and furniture was - 26,05 mln.USD for the year 2013 (PROCOMER, 2015).

Main export markets for primary wood products are the USA (28%), Singapore (26%), India (19%), Vietnam (8%), China (5%), Panama (4%), the UAE (4%), etc. in the respective order. However, Costa Rica itself is a big consumer of wood and it imports large amounts from Chile (55%), China (11%), the USA (5%), Spain (4%), Colombia (4%), Guatemala (3%), Honduras (3%) and others (Rodríguez & Alfaro, 2014) (See Figure 13).

The main commercial species are Teak *(Tectona grandis)*, Melina *(Gmelina arborea)*, Botarrama *(Vochysia ferruginea*), Gavilan *(Pentaclethra macrolob*a), Laurel *(Cordia alliodora)*, Roble Coral *(Terminalia Amazonia)*, Tamarindo *(Dialium Guianense),* Caobilla *(Carapa guianensis)*, Cedro Amargo *(Cedrela Odorata),* Eucalipto *(Eucalyptus sp)*, Pino *(Pinus caribea*), Pochote *(Bombacopsis quinata)*, Ciprés (Cupressus lusitanica), etc. (Rodríguez & Alfaro, 2014a).

[21] Average of 1990-2011

Figure 13. Main export markets of Costa Rican timber in 2013

Source: Rodríguez & Alfaro, 2014a

4.3 Forest governance

4.3.1 Administration

Costa Rica is one of the countries that underwent rapid land use changes between the 1950s -1990s due to agricultural expansion. As the result its forest cover reduced from 62.8% to 24% by the 1980s (Brown and Bird, 2011). However, the country was able to slow down the deforestation rate significantly and gain back its green cover through reforestation, especially due to the 1996 Forestry Law #7575 and its provision of payment to forest owners for conservation of forests. The current forest cover of the country is around 51% of the country's territory (The REDD Desk, 2015) (See Figure 12).

Nowadays, the forests are referred as valuable resources of the country and basis for a sustainable economy. The forest administration is comprised of different institutions gathered into the Costa Rican State Forest Authority. These institutions include the Ministry of Environment (MINAE), the National System of Conservation Areas (SINAC), the National Forestry Financing Fund (FONAFIFO)[22],[23], the National Commission for Sustainable Forestry, the National Forestry Office (ONF)[24], Forestry and Natural Resources Surveillance Committees (COVIRENAS)[25]. These organizations are intended to create a stable check and balances system and to maintain transparent forest administration.

[22] FONAFIFO is a forestry fund basically aimed at collecting resources and paying for PES national scheme.

[23] Both SINAC and FINOFIFO is reporting directly to Ministry of Environment.

[24] ONF is a non-governmental participatory body consisting of different private and NGO members.

[25] COVIRENAS is civil society group to conduct social supervision.

4.3.2 Control over timber harvest

The 1996 Forest Law requires from everyone who wish to harvest timber within the country's territory to obtain legal permits from national authorities. It identifies two kinds of areas: those where timber harvest is prohibited (protected areas) and those (private lands) where harvest is allowed but controlled by government (Forest Law, 1996). The legal procedures include various steps for different kinds of harvest areas:

1) If the area is a natural forest, then the forest owner needs to maintain a Management Plan (MP). It is developed by a professional forest engineer and aims to ensure sustainable use of the forests;

2) If the area is a pasture land, the document that is required is Forest Inventory (FI);

3) If the area is a plantation, then the harvester is requested to obtain the Certificate of Origin (CO) and is allowed to harvest without any restrictions.

The preparation process of these documents is assisted by professional forest engineers[26], independent forest professionals supervised by the College of Agricultural Engineers. The approval of harvest requests is performed by SINAC. Once there is an approval of the request, the forest owner must hire a professional engineer again to supervise the harvesting activity. After this, SINAC issues the timber harvesting permit (THP). Engineers make several audits to the harvesting area and each visit is followed by a report to SINAC (See Figure 14).

Figure 14. A Forest engineer (from FUNDECOR) is auditing the harvesting operation based on Management Plan and tree inventory. Sarapiqui, Costa Rica

Source: Photo by Aynur Mammadova

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[26] FUNDECOR can serve as an example of an organization that employs forest engineers

If there is no identified irregularity, SINAC issues transport permits (TTP) (together with plastic tags for each harvested log (see Figure 15)) to allow timber to leave the forest area to be processed in a sawmill. During this entire harvesting process SINAC itself can make visits to logging site to ensure fulfilment of regulations as well. Once the timber arrives at the sawmill, SINAC officials are supposed to make visits to ensure that all timber that arrives has tags and to collect used tags to prevent their reuse (Personal Communication, Miguel Araya, 17-03-2015).

Figure 15. From left to right- Management plan, plastic tags and Transport permit, Sarapiqui, Costa Rica

Source: Photo by Aynur Mammadova

The traceability of individual logs finishes once it is processed in a sawmill. However, the truck loaded with timber ready to be exported or for use inside the country, needs to have a transport permit with the information about volume and concession origin on it. This document can be checked by the National Police on the road or customs officers based on random checks (Personal Communication, Warner Porras Sánchez, 12-03-2015).

4.4 Timber illegality in Costa Rica

Despite the widely recognized green image of Costa Rica and long lasting efforts to preserve its forests, as in essentially all tropical forest countries illegal harvest and trade of timber still remains an important issue. According to official statistics, illegal trade (timber without harvest or transport permit) makes up to 25% of all traded timber, which is still lower than most of the Latin American countries around (SIREFOR, 2015). However, in personal interviews much higher percentage of illegality such as 35-40% was mentioned (Personal Communication, Herman Rodriguez Coffre, 18-03-2015). Besides, observations and analysis of the legality system helped to understand the seriousness of the problem in the country. The illegal timber trade in Costa Rica is not just a result of acts by criminal groups, but a complex issue deeply embedded into social and economic structure of the society and systemic failures in the governance mentioned by interviewees.

4.4.1 Forms of illegality

Illegality in the timber sector of Costa Rica happens in different forms. The following forms of illegality and their causes were identified via literature review and interviews held in Costa Rica and classified in the following order.

Harvesting

1. **Harvest of prohibited high value species from protected areas against Forest Law #7575-** The main species that are harvested illegally are Cocobolo (*Dalbergia retusa*)[27], Almendro (*Dipteryx panamensis*)[28], Cristòbal (*Platymiscium pinnatum*; *Platymiscium parviflorum*), Guanacaste (*Enterolobium cyclocarpum*), Laurel (*Cordia alliodora*), Cedro Amargo (*Cedrela odorata*), Caobilla (*Carapa guianensis*), Cola de Pavo *(Hymenolobium mesoamericanum*), Manù (*Minquartia guianensis*), Botarrama (*Vochysia ferruginea*), Gavilán (*Pentaclethra macroloba*), Nazareno (*Peltogyne purpurea*), Tostado (*Sclerolobium costaricense*), Guayacán Real *(Guaiacum sanctum)*. Out of this Tostado, Cristobal, and Cola de Pavo are the species mentioned in national Decree N° 25700-MINAE[29] as endangered, which means their trade is prohibited. Although the national protected area management is among the best in Latin America, these species happen to be harvested illegally in these areas. However, illegal cutting occurs in unprotected natural forest areas as well.

2. **Not respecting rest and recovery periods of the forest-** This case occurs when rules of sustainable management of forests are not followed and timber is extracted from private areas continuously without proper permit, not allowing the forest to replenish itself.

3. **Harvesting wrong/ extra species-** When the Management Plan is confirmed and the Harvest Permit is authorized, the owner of the forest gets approval to cut the tree species indicated in the inventory as the ones allowed to be harvested.

[27] CITES status- Appendix II

[28] CITES status- Appendix III

[29] Decree of the President of Costa Rica and Ministry of Environment and Energy on prohibtion of trade on endangered species, dating back to 1997

However, for generating extra income, trees that are not supposed to be harvested are cut as well. This also involves cutting immature trees with smaller diameter, as well as cutting more than the allowed 50-60% of the same species in the area.

4. **Land Use change-** As the legal harvest in natural forests requires many efforts and waiting periods, in many cases these forests are converted into pasture-land by gradually extracting wood from the area. Once fewer trees remain, the process of obtaining a harvest permit is relatively easier, as in this case the area would not be considered natural forest which would not require a Management Plan, etc. anymore (Personal Communication, Guillermo Navarro, 24-03-2015).

Processing and transport

5. **Mobile sawmills-** Extracting timber illegally in small scale with smaller equipment and processing it right in place in order to avoid any control at official sawmills**;**

6. **Use of plastic tags repeatedly-** in case the inspectors of SINAC do not arrive to a sawmill to collect used plastic tags, the sawmill owner can lend them to be reused in order to transport more timber "legally";

7. **Selling transport permits to unauthorised industry or using the same permit to transport more timber to a sawmill –** This case is similar to the previous one, however this time the transport permits are sold by timber owners to others to enable them to bring unauthorized timber to a sawmill; or they are used repeatedly by the same owner to bring extra loads of timber;

8. **Rapid processing of arrived wood in sawmills to lose the trace of illegality-** As traceability through plastic tags is lost once the logs are processed in sawmill, any illegal wood that arrives is processed quickly and mixed with legal wood before any inspection occurs;

Figure 16. Truck loaded with wood is leaving the forest area to bring logs to temporary storing place. Sarapiqui, Costa Rica

Source: Photo by Aynur Mammadova,

Export

9. **Exporting through unofficial trails-** Most of the illegal timber finds its way to other countries through unofficial trails without any checkpoints**;**

10. **Misusing random checks in customs point-** Currently timber is exported through the same customs points where any other export products are getting through as well. Due to loads at those points, the trucks and other vehicles need to move as soon as possible, thus checks are performed based on random selection. Every truck that arrives to a gate gets a signal similar to traffic light by pressing the button. If the colour is green they can go through without any checks, if it is red, then the necessary documents will be checked by officers. Those that cannot get through due to inconsistencies in their permits, etc. make short U turns and come back with the hope to get a green light next time. So that in the end all timber that is harvested gets exported;

11. **Covering the load of truck with fruits or sand in order to disguise the exported timber-** As Costa Rica is an important exporter of agricultural products such as pineapple, bananas, etc., in some cases these products are used to cover the timber in the lower part of the double floor truck and to export wood without any restrictions**;**

12. **Using truck containers and seals to restrict checks at customs point-** When exporters are using truck containers accompanied by seals, in most of the cases customs officers do not possess enough authority to request opening them at control points, as these containers are allowed to be open only once they arrive at their destination (Personal Communication, Herman Rodriguez Coffre, 18-03-2015)

13. **Accessing DUA (Customs documentation) without thorough checks-** the customs documentation can be easily obtained by entering necessary data on an online portal through a mobile phone and presented at customs check. Although it significantly facilitates the exporting process and reduces long waiting hours, it at the same time hinders proper checks by officials prior to issuing that document;

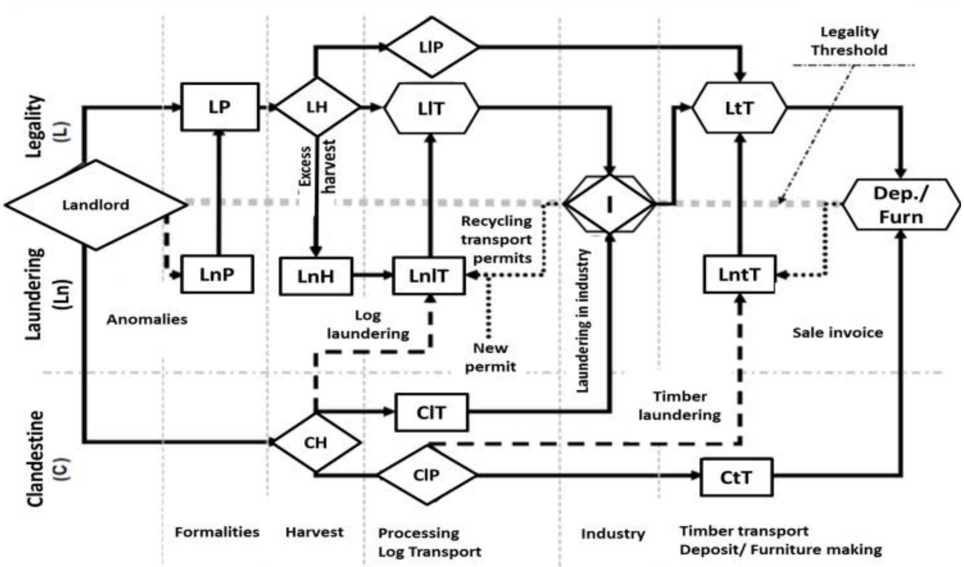
Internal market

14. **Showing different origin for wood in internal use-** The interviews with experts, as well as literature analysis have revealed that Costa Rica consumes the majority of the timber it is producing. According to ONF statistics in 2013 73.6% of all internally consumed primary wood products were produced locally (Rodríguez & Alfaro, 2014a). Moreover, it also imports lots of timber from neighbouring countries. In most of the cases, experts are not sure about the true origin of the imported wood species into Costa Rica. They fear that a certain amount of it originates from Costa Rica itself but is sold under a different origin. For example, harvesting Cocobolo (*Dalbergia retusa*) is strictly regulated in Costa Rica, meanwhile regulations in Nicaragua are not that strict. Thus, wood products made from Cocobolo usually indicate Nicaragua as an origin to avoid the strict control.

15. **Uses of timber for construction internally-** Constructions all over the country create great demand for wood. There have been identified cases when timber providers and construction managers reach agreements for fast and direct supply of timber without any documentation.

As an alternative to this classification, Navarro et al. (2006) describes the forms of timber trade in Costa Rica in its three forms: legal, clandestine and "legalized"/laundered. Figure 17 describes different forms of timber supply chain in Costa Rica, as well as the ways of legalizing illegal timber. In the first scenario, which is described in the upper part of the scheme, the Landlord acquires a legal permit (LP), then implements the legal harvest (LH) after which the logs are either transported (LlT) to industry or get processed (LlP) and transported in form of processed timber (LtT) for different uses.

The chain of clandestine/pure illegal harvest is described in the lower part of the scheme. In this case, harvest is performed without any permit (CH), logs are processed into timber (ClP) and transported secretly (CtT) for the direct use in furniture making, etc.



1) LP-legal permit, LH-legal harvest, LlT-legal log transport, LlP-legal log processing, LlT-legal timber transport, Dep./Furn- Deposit/Furniture making;
2) CH-clandestine harvest, ClP-Clandestine log processing, ClT-clandestine log transport, CtT-Clandestine timber transport;
3) LnP-Launder permit, LnH-launder harvest, LnlT-laundered log transport, LntT-Laundered timber transport

Figure 17. Legal and illegal timber supply chain in Costa Rica.

Source: Adapted from Navarro et al., 2006.

"Legalization", thus laundering of timber occurs in different forms and the supply chain of legal timber can be contaminated in different stages (described in the supply chain in the middle). In the first stage, the landlord can obtain an unofficial and illegal permit (LnP) and add it to their legal permits. In the second stage, excess harvest can occur that is not allowed by legal harvest permits, thus the additionally cut timber (LnH) finds its way into transport of legal logs (LlT) with the help of recycled transport permits provided by sawmills that collect them and do not submit them back to SINAC (or the same legal permit is used repeatedly to bring excessively cut timber). At this point, legalized/ laundered logs can also be further contaminated by totally clandestine logs and these find their way to legal transport trajectory as well. The fifth phase describes how industry can accept pure clandestine timber without any transport permits (ClT). In the sixth phase, the processed clandestine logs (ClP) travel all the way to the legal timber transport trajectory (LntT) with the help of sales invoices issued by the depository. The scheme shows that the issue of illegal harvest and timber trade is quite complex and multifaceted. The personal interview with the author has revealed that the situation stays the same in Costa Rica despite the fact that around 10 years have passed since the scheme was developed (Personal Communication, Guillermo A. Navarro, 24-03-2015).

Besides this, illegality in the timber sector was identified in two main forms during interviews: pure illegality and administrative illegality. Pure illegality occurs when no permit has been issued for the harvest, since the harvest area or the specie is protected. Administrative illegality occurs when harvesting certain wood is not against the law itself, however, administrative burden and long waiting period encourage owners to proceed without proper documentation.

4.4.2 Causes of illegality

The causes of timber illegality in Costa Rica were revealed through literature review, interviews, and observations during field visits, discussions with forest engineers and owners, etc. In order to present a more systematic view they are grouped into Technical, Financial and Structural limitations.

Technical

1) **Inability to recognize specie of the tree while standing as well as after they are felled in the form of timber**, creates an opportunity for laundering of wood that is cut extra or replaced by those that are originally planned to be cut according to Management Plan. Costa Rica is home to 2000 tree species, most of them being commercially logged. Most of the species look similar and the untrained eye can easily confuse them. This creates challenges at Customs check points as well;

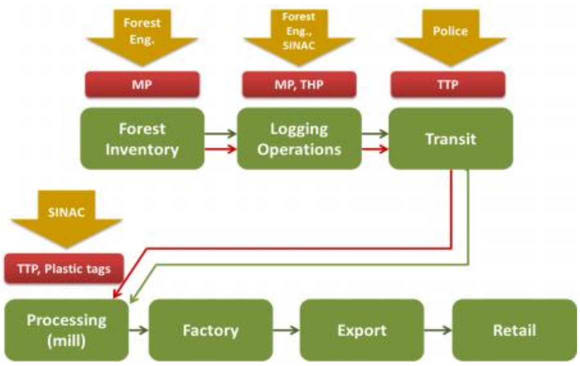


Figure 18. Typical supply chain of wood (from natural forest).[30]

[30] Red lines indicate the chain controlled by Costa Rican National system, yellow shapes show actors controlling each phase, red ones represent required documents during control

2) **Lack of tracebility of each logged tree within the forest-** The plastic tags obtained from SINAC are fixed on timber after it is brought to a temporary place and once it is ready to leave the forest (See Figure 19). Thus, the link between each logged tree specie and tag gets lost, creating further loophole in the system.

3) **The design of the current national legality verification system favors incomplete supply chain management.** The controls by SINAC and checks on legality are done only in the concession area and sawmills, and on the way between them. The tracebility scheme developed by the government ends once the log is processed in a sawmill and the tags are collected by SINAC officials. Thus, once a log is processed it loses the link to its source and is not traced back anymore. After the sawmill, the transported timber is just accompanied by a simple transport permit indicating its volume and source. Figure 15 presents the typical supply chain of wood. While typical supply chain usually involves seven separate phases, the national legality verification system of Costa Rica is designed to check on only first four phases (Personal Communication, Pedro Gonzalez Chaverri, 17-04-2015).

Figure 19. Harvested wood is piled together in temporary place in a forest, where it is documented, marked with plastic tags and made ready to leave the concession area. Sarapiqui, Costa Rica

Source: Photo by Aynur Mammadova

Financial

1) Most of the interviewees named **Poverty** as the main driver of illegal logging (especially within protected areas) in remote areas and the reason why people take the risk of harvesting timber in highly controlled areas and being fined or jailed;

2) **Accessing legality is highly costly for forest owners, which means the system incurs high transaction costs** (See Annex B). Approval of a simple management plan or obtaining harvest permit from SINAC takes a long time, e.g. up to one year period. The legal performers have 30-60% higher in total costs than illegal actors (Navarro and Thiel, 2007). Thus, those who originally wish to do business through legal ways, end up with higher costs, while illegality can be done with much lower spending. According to a study done by CATIE, up to 62% of illegality in Costa Rica occurs in cases where the harvesting is done according to legal standards, and proper documents could be obtained (2001). Compared to the 38% of cases of pure illegality (where no legal permit could be issued according to Forest Law), administrative illegality is quite high and shows unwillingness of concession owners to go through the bureaucratic procedures. Thus, a robust control system creates perverse incentives for forest owners and shows that the current system is not cost effective.

3) **Lack of resources and staff in SINAC** (the organization responsible for policing the forestry sector in Costa Rica) has become a major reason for irregularities and illegalities. Although the organization is very strict during their checks and controls, it might quite be the case that noone from SINAC arrives to the forest and checks that harvesting is done according to management plan. This is due to a lack of staff members in each regional office of SINAC and overload of the officers with additional tasks.

4) **Lack of financial independence** of controlling organizations such as SINAC is claimed to be very important for the full functioning of the system. According to Forest Law # 7575, the activities of SINAC were originally planned to be funded by forest tax[31], paid by industries. However, challenges in defining the baseline for collecting the tax has led to the situation that it is not collected any more. This has greatly affected financial independence of SINAC and its resources at disposal. Moreover, the situation encourages officials to accept food and transport from forest owners when they make field visits and checks (Brown et al. 2008; Personal Communication, Herman Rodriguez Coffre, 18-03-2015).

Structural

1) **The legality verification system designed by the government and SINAC aims to check only legal and declared activities.** In other words, the timber that is smuggled in clandestine ways (refer to Figure 13) passes through without being registered or punished. This in its own turn puts more pressure on legal actors and creates the feeling of discriminative treatment.

2) **The structure of SINAC has allowed each regional office to act autonomously**. 27 regional offices of SINAC act independently and all maintain their own databases. Although it creates great flexibility, lack of efficient central control on regional offices leads to limited exchange of information among them.

3) **Inconsistent visits of SINAC officials to sawmills** are the main reason that illegalities such as reuse of transport permits and plastic tags occur. Making use of

[31] 3% of the transferred value of the logs at the moment of primary processing

opportunity, sawmill owners can lend permits to bring more, but unauthorized timber to the place, and quickly process them once they arrive.

4) **Police control on the roads to check Transport Permits (TP) is performed independently from SINAC**. There is no exchange of information and coordination of actions between these two controlling bodies. On the road the duty of the police is simply to check the documents and it has no capacity to verify neither the species nor the volume of the transported timber. Moreover, trucks loaded with timber are not required to stop at police control points and are checked on random basis (Brown et al., 2008).

5) **One window system for exported products, as well as inability of customs officiers to distinguish timber species, crosscheck and verify the species declarations** allows all forms of extracted timber to get exported.

6) Unfortunately, **illegal timber harvest and trade is not prioritized within the judicial system of the country**. It is still not considered an important crime while there are other urgent issues to be dealt first, such as drug smuggling, etc. There are only 3 state environmental prosecutors in the country. Forest Law 7575 states illegal timber trade as a penal and criminal crime and defines from 3 months up to 3 years of imprisonment, as well as confiscation of machinery and equipment. However, this is rarely enforced. In most of the cases, offenders get around with softer penalties or the cases last so long that they lose their relevance (Personal Communication, Herman Rodriguez Coffre, 18-03-2015).

7) **The Forest Law of 1996 is outdated**; it discriminates against small forest owners and does not reflect the realities of the current time. It has several gaps in its processes for identifying land titles (Personal Communication, Guillermo Navarro, 24-03-2015).

8) **The role of forest engineers as controller and manager of harvesting operations is confusing**. Firstly, because they develop management plans for forest owners and control their implementation themselves (Personal Communication, Herman Rodriguez Coffre, 18-03-2015). Second, they are hired and paid by forest owners, which might lead to conflicts of interest (Brown et al., 2008).

In the view of successes and challenges of forest governance in Costa Rica and an attempt to classify the forms and causes of timber illegality, the next Section aims to analyse at which levels DNA tracking technologies can contribute to address the issues.

5 DNA technologies in the case of Costa Rica

5.1 Hypothetical levels

The match between above mentioned limitations and the possibilities of DNA technologies reveals that application of the technology can generate positive externalities for all three -Technical, Financial and Structural limitations. However, due to the fact that genetic timber tracking methods remain technical solutions, they address the first group of limitations directly. The analysis of this Section is performed purely on hypothetical basis according to limitations of the system described above. They are presented as technically feasible solutions without yet adding a discussion on feasibility, market availability or cost effectiveness.

DNA barcoding

As mentioned previously, in most of the cases timber illegality in Costa Rica originate from the fact that similar looking species cannot be differentiated at different phases of supply chain. As a result, willingly or unwillingly the supply chain becomes contaminated by wood that was not supposed to be harvested. DNA barcoding, in other words species identification using DNA markers, might help to address this issue with a high degree of precision. DNA barcoding can be applied in the following cases in the context of Costa Rica:

1) Development of more precise inventory of trees in protected areas to help to identify and manage biodiversity;

2) Development of more precise inventory by forest engineers as a part of the Management Plan. Identifying which trees depend on each other for faster growth, cross polinization, to make sure they are not harvested[32];

3) Verifying the claims and documentation on species at sawmills by SINAC, on the road by police, at construction places by SINAC and at export point by customs officers;

4) Using as evidence for court cases involving illegal harvest and trade of timber.

Population genetics

1) When it comes to timber illegality the analysis of population genetics is usually used at import points, in order to verify or disprove the origin of wood. Due to the fact that the USA (not the EU) is the main importer of the Costa Rican wood, the application of the technology will be highly dependent on its wide spread adoption by the US government.

[32] Application of genetic identification of plant species for the purpose of sustainable forest and biodiversity management is older than its application as forensic method (Personal Communication, Marius R.M. Ekué, 20-03-2015).

2) As mentioned previously, Costa Rica is also a major importer of wood from countries like Chile, Nicaragua, etc. The experts fear that in many cases the products with foreign origin in fact might originate in Costa Rica (e.g. furniture made from Almendro (*Dipteryx panamensis*)[33] with the declared origin of Nicaragua, where unlike Costa Rica the trade of the specie is not regulated). Thus, DNA analysis present a great technical opportunity to check on these suspicious products on the market, make frequent raids to the main wood product markets or check them even at the point of import.

DNA fingerprinting

1) Private companies that source from Costa Rica can apply DNA fingerprinting to strengthen their supply chain and avoid the entry of illegal timber to the system;

2) Certification companies, such as FSC might use DNA fingerprinting methods during their audit visits to check on sustainability of "controlled wood" originated from this area.

The analysis of these hypothetical cases shows that there are relatively more areas of application where DNA barcoding can be useful rather than others.

5.2 PESTLE - Feasibility analysis

This Section aims to discuss the practicality of the hypothetical considerations mentioned previously. Based on literature review and expert opinions this analysis employs PESTLE framework to describe the political, economic, social, technological, legal and environmental context in Costa Rica around the issue of applying DNA tracking technologies. Figure 20 summarizes the revealed aspects within the framework. While white coloured shapes describe drivers, dark blue shapes stand for barriers on the way of employment genetic timber tracking methods in national legality verification system of Costa Rica. During the interviews respondents were asked to name main drivers and barriers of the application of the technology and classify them further from most to least in importance. The results are given in Figures 21 and 22.

Political.

1. When it comes to applying DNA technologies within a national legality verification scheme, there is enough political will for testing this new idea. Edgar Gutiérrez, Costa Rica's new Environment Minister who was appointed in May, 2014 is considered to be eager to bring new changes to the environmental strategy of Costa Rica. He has a background in Forest Biometry and according to interviewees, is open to new ideas, especially those about applying scientific

[33] CITES status- Appendix III

methods at an operational level (Personal Communication, Herman Rodriguez Coffre, 18-03-2015).

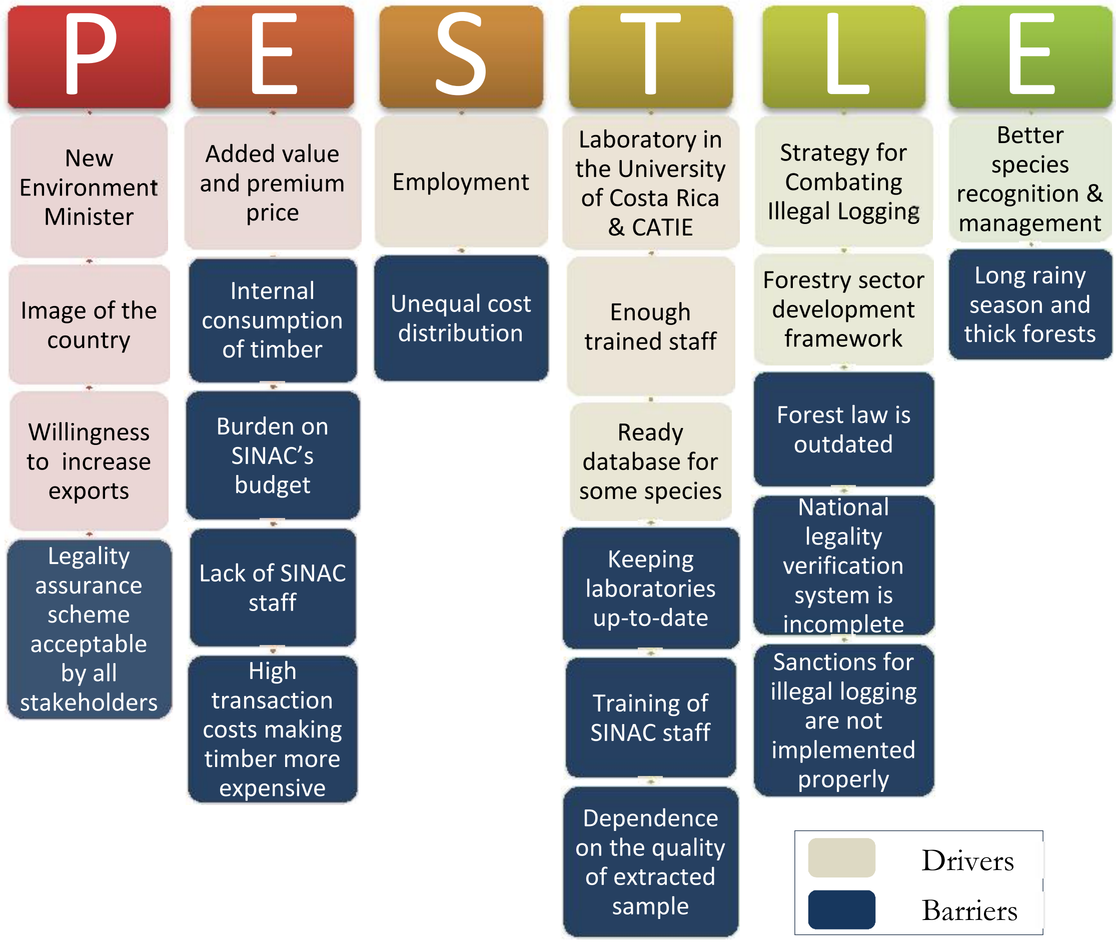


Figure 20. PESTLE analysis for application DNA technologies in the case of Costa Rica

Source: Own elaboration

2. The country has always been proud of being a birthplace of innovative approaches in environmental management, from where these approaches have spread all over Latin America. Testing the feasibility of DNA technologies at national level would help the country to maintain that image.
3. "Lines of Action for Implementing the Policy of Forest Development in Costa Rica 2014-2018" (Lineas de Accion para implementar la Politica de Desarrollo Forestal de Costa Rica 2014-2018) is yet another driver for the possible application of DNA technology, as its article 4 emphasizes the importance of developing and implementing a new system of traceability and legality verification for forest products. The document is written in a spirit of conservation of the country's

forests, while at the same time seeking to increase the legal consumption of wood and reviving the forest industry (MINAE, 2014).

4. However, the document clearly states that the traceability scheme should not affect the competitiveness of the sector and be accepted by all relevant stakeholders.

Economic

1. The current forest strategy of the country is concentrated on the revival of the timber industry and finding new markets for Costa Rican wood (Personal Communication, Sebastian Ugalde Alfaro, 18-03-2015). By applying DNA tracing technologies and increasing its export to Europe or the USA, there may be opportunities for Costa Rica to reap extra benefit from these sustainability oriented markets.
2. However, there are great economic barriers too. Currently, more than 70% percent of the produced wood is consumed locally. Thus, there are limited incentives to use the technology for exporting purposes. Besides, it is not clear to what extent the application of DNA would affect the overall timber illegality in the country, if it is applied for the purpose of export to other countries.
3. Costa Rican timber is already expensive due to high labor costs in the country, which makes it difficult to compete in international markets against wood from China or Vietnam. Applying DNA in the supply chain would further increase the price and push Costa Rican timber further toward niche markets.
4. Moreover, and as mentioned previously, high transaction costs are a major reason for administrative illegality in the country creating perverse incentives for forest owners and industry. Thus, adding extra costs and procedures might increase bureaucracy and illegality even further.
5. Pertinent across many levels, an important barrier to application of the technology is the lack of resources of SINAC. As mentioned previously SINAC's budgetary dependence creates problems even in the current verification system. Application of DNA at national verification system would require major investments, which currently cannot be made without large donor funding (See Annex C). Adding costs of sampling of species in natural forests and protected areas, developing markers and ongoing tests during field visits would create further dependence on central governmental budget.
6. A lack of staff in each regional office of SINAC limits the ability of extracting necessary samples at a continuous fashion.

Social

1. Opting for DNA tracing technologies could create extra jobs for forest technicians, laboratory workers, and administrative staff and add to overall welfare.
2. However, the system would need to be designed and implemented carefully, not to discriminate against poor and not to put the costs of applying the technology on forests owners - those parties, who according to Guillermo Navarro have always been discriminated during formulation of forestry strategies and programs (Personal Communication, 24-03-2015).

Technological

1. There has already been some previous work on DNA tests for identification of species in Costa Rica and Central America (Cavers et.al, 2003; Cavers et.al., 2005; Gillies et.al., 1999; Navarro et.al, 2005; Novick et.al., 2003). There are already ready genetic databases for around 8 timber species in Costa Rica that can serve as the basis for further reference database development[34].
2. The Forest Products Laboratory in the University of Costa Rica (San Jose) served as the main hub for these analyses. The laboratory currently possesses all necessary equipment for performing DNA tests of wood. Besides, there is a small laboratory at the Tropical Agricultural Research and Higher Education Center (CATIE) which is located little further away from the capital in the city of Turrialba. According to conservationist and forest scientist Carlos Manuel Navarro, there are adequate numbers of educated staff at these laboratories to conduct tests in case of necessity and short training to update their knowledge on current developments in the sphere would be sufficient (Personal Communication, 22-04-2015).
3. In this context, the main technological barriers would be the maintenance of the laboratories, as well as the technical training of SINAC staff on proper and careful extraction and deposit of DNA samples during their filed visits.

Legal

1. The above mentioned "Lines of Action for Implementing the Policy of Forest Development in Costa Rica 2014-2018" as well as previous "Strategy to Control Illegal Logging 2002-2007" create a favourable legal environment for the application of the technology.
2. However, due to the fact that Forest Law of 1996 is outdated and has some gaps in the definitions, bringing DNA technology in the context of this law would be challenging.
3. In addition, the Law enforces roles and responsibilities around an incomplete supply chain, which makes it very difficult to apply DNA in all stages of the supply chain from forest to the end consumer.
4. Moreover, although the law clearly identifies the legal punishment in cases of illegal logging, it is enforced very poorly. This generally undermines the whole purpose of applying new technology for checking on illegality.

Environmental

1. Genetic methods can provide precise species identification and consequently to sustainable forest management.
2. The long rainy season (from late April till December), as well as thick rainforests could make sampling work lot more challenging and affect the quality of the collected samples.

[34] Swietenia macrophyllla, Cedrela odorata, Hyeronima alchorneoides, Lonchocarpus costaricensis, Vochysia ferruginea, Vochysia guatemalensis, Ulmus mexicana, Cordia alliodora (Personal Communication, Carlos Manuel Navarro, 22-04-2015)

5.3 Results and weighting

In view of all mentioned drivers and barriers within PESTLE, this section aims to assess their importance and urgency. To this end, interview records were used to analyze how often which factor was mentioned by the interviewees. As the interviews mostly employed open questions, there was not any premade list of factors. Each interviewee was asked to name drivers and barriers that they would think of. Then they were further asked to weight them according to values from 0 to 5[35]. This kind of weighting helped to reveal the importance of each factor and add some justification to the results that otherwise would have depended solely on perception of the author.

# of Mentioning of Drivers	
Political	
New Environment Minister	*2*
Image of the country	*3*
Willingness to increase exports	*9*
Economic	
Added value and premium price	*6*
Social	
Employment	*1*
Technical	
Laboratory in the University of Costa Rica & CATIE	*4*
Enough trained stuff	*2*
Ready database for some species	*2*
Legal	
Strategy for Combating Illegal Logging	*4*
Forestry sector development framework	*3*
Environmental	
Better species recognition & Management	4

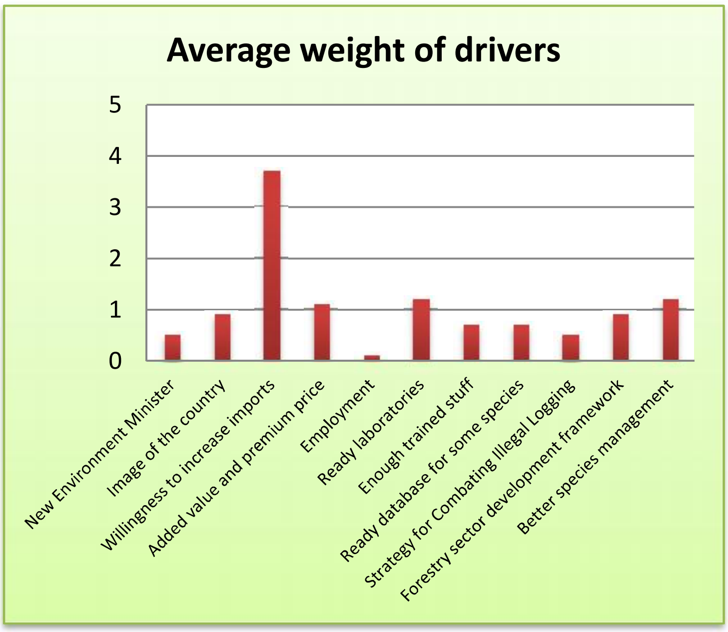


Figure 21. Drivers, the number of interviewees and their average weight

Figure 17 illustrates the number of respondents mentioning each driver. The weights given by respondents are analyzed though calculating an average value for each driver. As the chart also shows, the informants of this study indicate that political will for increasing timber markets and legal consumption of wood in the country, as well as availability of DNA laboratories and potential contribution to sustainable forest management were relatively more important among the drivers mentioned.

[35] 0-least, 5-most important one

# of Mentionings of Barriers	
Political	
Legality assurance scheme acceptable by all stakeholders	*6*
Economic	
Internal consumption of timber	*9*
Burden on SINAC's budget	*9*
Lack of SINAC staff	*7*
High transaction costs making timber more expensive	*9*
Social	
Uneven cost distribution	*4*
Technical	
Keeping laboratories up-to-date	*3*
Training of SINAC staff	*4*
Dependence on the quality of extracted sample	*5*
Legal	
Forest law is outdated	*8*
National legality verification system is incomplete	*8*
Sanctions for illegal logging are not implemented properly	*6*
Environmental	
Rainy seasons	6

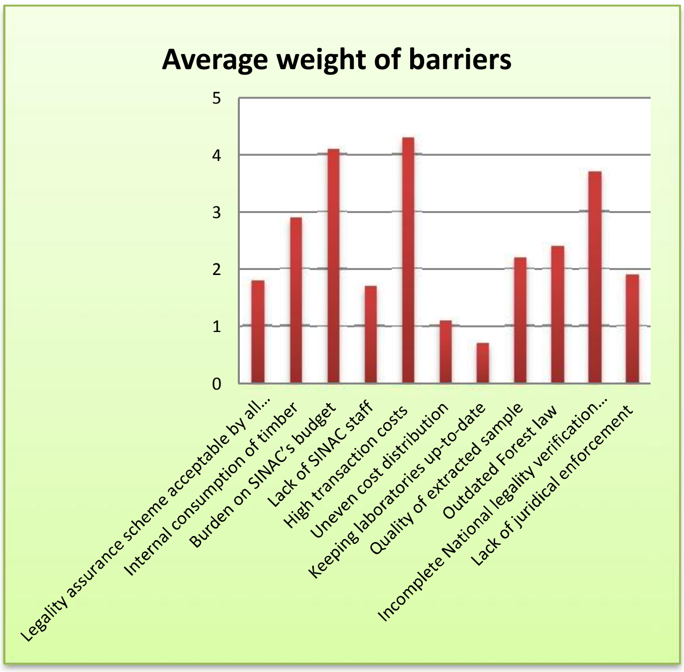


Figure 22. Barriers, number of interviewees and their average weight

Figure 18 illustrates the main barriers, the number of times they were mentioned, as well as their average weights. As it is clear from the chart, economic barriers such as adding to already existing high transaction costs, to a burden of SINAC's budget, as well as incomplete structure of the system were weighted more than the rest.

In general, barriers for the application of the technology were mentioned more often and weighted more severe than drivers by interviewees. This helps to conclude that the potential technology application in this country will face serious challenges on the way.

6 Conclusion & Discussion

6.1 Reviewing research questions

In view of the content of this analysis, this chapter refers back to each research question individually and summarizes the main findings of this work both in the international context and in the case of Costa Rica.

RQ1a. *Why does illegally harvested timber find its way into global markets? What are the limitations of existing public and private legality verification systems?*

- ✓ Literature review helped to reveal that global forest governance can be classified mainly as international, (mostly) bilateral legality verification systems, domestic/government, self-governance (forest certification) and communal. Among them forest certification and legality verification systems are considered the most recent ones.
- ✓ Due to complexity of the issue, all initiatives face challenges at different levels in their attempts to address forest illegality and sustainability. Ineffectiveness, lack of enforcement resources, corruption, narrow focus, transparency, etc. are identified as the main loopholes of the systems responsible for assuring legality of the traded timber. NGO reports serve as excellent reference documents in search for examples for such limitations.

RQ1b. *What are the current developments in genetic tracking methods, how does it function, what are the future opportunities, drivers and barriers for its wide spread application?*

- ✓ Timber tracking based on genetic methods is considered the most accurate and trustful, as DNA is impossible to falsify unlike usual documentation or tags. However, the technique is not universal; it cannot be applied for example for paper and pulp products. Genetic methods can be applied in three areas for the purpose of tracking timber: DNA barcoding for species identification, Population genetics for identifying geographic origin and DNA fingerprinting for Chain of Custody verification. The studies during the last 15-20 years have helped the technology to prove itself as a standalone method.
- ✓ Currently there are several research institutes working on genetic methods for timber and exploring new opportunities. Among those the Thünen Institute in Germany and the Australian Centre for Evolutionary Biology and Biodiversity in Adeilade University are the most specialized ones. NGOs such as WWF, the IEA(International Envistigation Agency) openly support the technology application. Double Helix is the main private organization licensing the technology and offering different services to clients based on DNA analysis of timber. Besides, there are few private companies in the EU, the USA and Australia making use of the technology in their supply chain management. The technology slowly starts gaining interest by

certification and accreditation organizations and used by governments of EU countries to verify claims.

- ✓ Main drivers and barriers for its wide spread application can be classified as external and internal. New timber regulations and their strict control systems (such as the EUTR (2013) in EU, the Lacey Act (2008) in the USA, the Illegal Logging Prohibition Act (2012) in Australia, etc.), the possibility of green branding and opportunity to gain new markets, increasing pressure from NGOs, future expectations in cost reduction, transformation into highly automated process and the current development of more detailed global databases serve as main drivers for the technology. Unequal enforcement of legislations (especially in EU), limited knowledge of public in large about the technology and its possibilities, current high costs, lack of global reference maps for all species, existence of few laboratories and the preference (of mostly domestic governments) to have fast, on time and locally performed control system create major barriers for the technology application.

RQ1. *How (at which levels and context) can DNA timber tracking methods assist existing governance systems? What does the technology offer?*

- ✓ The analysis of case studies on timber illegality (presented in the reports of different NGOs) compared to the possibilities of genetic methods showed that the technology has potential to tackle illegal timber trade on different levels. Those include false geographic origin declarations, extraction of valuable species, and harvesting outside of legal concessions. Thus, the technology represents a reliable enforcement tool.

RQ2. *What are the main challenges related to combat illegal logging in Costa Rica and how can the technology be applied in the national legality verification system in this country?*

- ✓ Despite the widely known green image of Costa Rica and its long history of forest conservation, illegal harvest and trade remains important issue in the country. Timber illegality is claimed to comprise 35-40% of totally traded timber in the country.
- ✓ There is a system in place established by the Forest Law of 1996 to ensure sustainable and legal use of forests. However, the system experiences several limitations due to identified technical, financial and structural challenges. Several forms of illegality were identified in the harvesting, processing, transport and export phases of the supply chain. Inability to recognize wood species at different stages, repetitive use of transport permits, incomplete supply chain management, financial dependence of SINAC - the governmental body responsible for surveillance, lack of coordination between police and SINAC, high transaction costs for accessing legality, etc. are revealed to be the main causes for illegality.
- ✓ Currently the country aims to reconsider its forest strategy, increase wood exports and apply new tools for tracing wood and wood products. Hypothetically, DNA methods can enhance existing system through different scales of application.
- ✓ Political, environmental, social, technological, legal, and environmental aspects (PESTLE) helped to shape the overall image around the possibility of applying the

technology in the national legality verification system of Costa Rica. The study showed that political will for increasing timber markets and legal consumption of wood in the country, as well as the availability of DNA testing laboratories and potential contribution to sustainable forest management weighted more among other mentioned drivers. Economic barriers such as adding to already existing high transaction costs, to a burden of SINAC's budget, as well as incomplete structure of the system were weighted more than the rest. In general, barriers were mentioned more than drivers for the application of the technology in the national legality system of Costa Rica.

6.2 Limitations of the DNA technologies

Despite being considered an important breakthrough in the combat against illegal logging, the technique can remain a reactive measure, instead of being proactive. The legality of timber is mostly checked after it was already felled. Thus, in case of inconsistent application, its ability to serve as abstaining measure and help to save global forests might be limited.

Moreover, DNA technologies are designed to check on legality of the traded timber, and do not necessarily help to identify sustainability of the forest management and supply chain. Currently, they are mostly employed as practical tools within legality verification systems mentioned in the literature review. Thus, the positive effect of the technology on sustainability might be only possible through inclusion of more sustainability conditions into the definition of forest legality in both developed and developing countries.

Applying DNA technologies will bring more pressure on legal actors due to increased transaction costs, meanwhile its role to prevent clandestine timber- the one that is harvested, processed and traded in clandestine way without being declared at any point and passed through unofficial trails (especially in the case of Costa Rica) still remains a question.

There is still a very obvious hesitant attitude toward the technology. Due to being commercialized very recently, companies are unsure about new market opportunities that the application will bring. Besides, governments are cautious about bringing technological solution to a deep social and economic problem, as well as allowing private interests to get involved in policy making.

No matter how appealing it sounds, the resilience of the technology is still under question. The effectiveness of DNA technologies to combat illegal logging will always depend on the context of the legality verification system, the readiness of a country, and the capabilities of the individuals operating the technology. As one of the interviewees mentioned, bringing the technology to Costa Rica would be similar to bringing a Formula 1 car to the Amazon forest and attempt to drive it. Thus, although the technology might present excellent opportunities in a stand-alone fashion the context in which it is applied remains an important issue if large scale application is to be achieved However, the Costa Rican case should not be generalized, as the success of the technology depends on each local context, where DNA methods might fit better or worse.

6.3 Discussion

Key observations

Currently, there is a big dilemma in forest governance around the world. On the one hand, tighter regulations and strict check and controls are demanded by those who consider that national legislations, certification bodies are lax in their requirements (e.g. the case of FSC Mixed wood). On the other hand, there are lots of proponents of the idea that, tighter regulations create high transaction costs, perverse incentives and more illegality. It also leads to erosion of trust that traditionally was developed between forest owners and their customers, thus more tendency to cheat the system. The effect of DNA technologies on this debate still needs to be clarified.

This research topic was initially raised out of curiosity – seeking to understand why in the context of climate change and rapid loss of biodiversity, governments, institutions, private businesses do not sufficiently employ the possibilities of DNA tracking technologies to the extent it offers. The initial literature review on technology development and identification of different cases of timber illegality around the world seemed to create a perfect match, where the challenges could be addressed through DNA analysis and problems could be solved. The detailed case study in Costa Rica and long discussions with local experts in the country have helped to avoid this kind of naïve and hasty conclusion for the research and understand that there is not one simple solution to the deep socio-economic problem which reveals itself in the form of illegality in the forest sector. Thus, this study has shown that case studies present great experience to test the theory and understand the larger context surrounding the issue.

The analysis part presented in Chapters 5, as well as costs of application of technology in the case of Costa Rica (Annex C) present the author's own elaboration based on previously obtained information and were not reviewed and commented by experts who have accumulated knowledge and expertise in the application of DNA tracking technologies throughout the years. However, this project has played a catalysing role in establishing contacts between professional institutions specialized in DNA technologies and local non-governmental organizations in Costa Rica such as FUNDECOR[36], where the author has accomplished her research internship for 2 months. Observation of the further development of cooperation and possibility of implementing pilot projects in the field might add further value to the research project in the future. Thus, the results of this research might be of value for local stakeholders in Costa Rica, as well as for organizations promoting the technology.

[36] FUNDECOR is also one of the main organizations mentioned in the document "Lines of Action for Implementing the Policy of Forest Development in Costa Rica 2014-2018 " acting as a consulting body to the Ministry of Environment in the process of development of new forest strategy and timber tracking system.

6.4 Choice of methodology and suggestions

The full application of the Technological Innovations System framework could have added to the results for Chapter 3. However, the main focus of the thesis was not the technological status, but the possibilities of application of genetic timber tracking methods. Thus, the focus was shifted more towards the case study. Completing the entire framework for this technology is an interesting opportunity for future research.

The comparative study of other cutting edge timber tracking technologies and their PESTLE analysis in the case of Costa Rica can increase the understanding of strengths and weaknesses of each methods and their applicability in the case of Costa Rica. Future researches in the field might consider this as a starting point of their investigation.

6.5 Recommendations

General

The results of this study might be used to identify the leverage points for changes by relevant actors wishing to promote the application of this technology. As the study suggests, necessary emphasis should be put on the efforts to simplify the process through further technological developments, which is believed to reduce costs as well. This would help increase the acceptance of the technology in countries like Costa Rica, where there is a will for application of innovative approaches, but not enough resources for that purpose.

Costa Rica

The recent statistics show that, there is a reduction in export volumes of teak (main exported timber in Costa Rica) in recent years, mainly because reforestation capabilities cannot compete with logging rates. There is a drop in revenues as well. Thus by implementing tracking system such as DNA fingerprinting, Costa Rica can suffice with logging less, but getting premium prices for its products in the USA and Europe, where regulations are strict and companies are searching for legal products to comply with legislation.

By becoming a member of ITTO, Costa Rica might benefit from project funds of this organization. The country also might benefit substantially from establishing VPAs with EU in order to access extra markets, but where legality is required.

Bibliography

Agrawal A., Chhatre A., Hardin R. (2008). Changing governance of the world's forests. *Science,* 320 (1460–1462)

Akella, S., & Cannon J. (2004). *Strengthening the Weakest Link—Strategies for Improving the Enforcement of Environmental Laws Globally*. Center for Conservation and Government at Conservation International, Arlington, VA.

Andreasen, K. P., & Sovacool, B. K. (2015). Hydrogen technological innovation systems in practice: comparing Danish and American approaches to fuel cell development. *Journal of Cleaner Production*, 94, pp.359-368.

ASI (Accreditation Services International). (2014). *Traceability and Forensics Procedure.* Retrieved from http://www.accreditation-services.com/archives/asi-traceability-and-forensics-procedure-approved.

Asif, M.J. & Cannon ,C.H. (2007). DNA extraction from processed wood. A case study for the identification of an endangered timber species (Gonystylus bancanus). *Plant Mol Biol Report,* 23, pp.185-192.

Bass, S., Thornber, K., Markopoulos, M., Roberts, S., Grieg-Grah, M. (2001). Certification's Impacts on Forests, Stakeholders and Supply Chains. *Instruments for Sustainable Private Sector Forestry Series*. International Institute for Environment and Development, London, pp. 134.

Bennett, E.L. (2001). Timber certification: where is the voice of the biologist? *Conservation Biology* 15 (2), pp. 308– 310.

Bergek A., Jacobsson, S., Carlsson, B., Lindmark, S. & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, 37(3), pp. 407-429

BMELV (Federal Ministry of Food, Agriculture and Consumer Protection of Germany) & Thünen Institute for Forest Genetics. (2013, March). *The fight against illegal logging*. Press Release. Retrieved from http://www.ti.bund.de/media/ti/Infrastruktur/Thuenen-Kompetenzzentrum_Holzherkuenfte/Pressemappe/130225_BMELV_TI_PRESSEMAPPE_en_2_Bekaempfung_FINAL.pdf

Botanic Gardens Conservation International (BGCI). (2007). *Tree-BOL to Barcode World's 100,000 Trees*. Retrieved from https://www.bgci.org/resources/news/0463/

Bounds, G. (2009, April 2). As eco-seals proliferate, so do doubts. *Wall Street Journal.* Retrieved from http://www.wsj.com/articles/SB123862823846680371

Brown, D., Schreckenberg, K., Bird, N., Cerutti, P., Del Gatto, F., Diaw, C. & Wells, A. (2008). *Legal timber. Verification and governance in the forest sector.* Overseas Development Institute, London.

Brown, J., & Bird, N. (2011). *Costa Rica's sustainable resource management: Successfully tackling tropical deforestation.* Overseas Development Institute (ODI). Retrieved from http://www.developmentprogress.org/sites/developmentprogress.org/files/costa_rica_report_-_master_0.pdf

Cashore, B., Auld, G., & Newsom, D. (2004). *Governing through markets: Forest certification and the emergence of non-state authority*. New Haven: Yale University Press.

Cashore, B., & Stone, M. W. (2012). Can legality verification rescue global forest governance?: Analyzing the potential of public and private policy intersection to ameliorate forest challenges in Southeast Asia. *Forest policy and economics*, 18 pp.13-22.

Cavers, S., Navarro, C., Hopkins, P., Ennos, R.A. & Lowe, A.J. (2005). Regional and population scale influences on genetic diversity partitioning within Costa Rican populations of the pioneer tree Vochysia ferruginea Mart. *Silvae Genet*, 54, pp. 258–264.

Cavers, S., Navarro, C. & Lowe, A.J. (2004). Targeting genetic resource conservation in widespread species: a case study of Cedrela odorata L. *Forest Ecology & Management*, 197, pp. 285–294.

CertiSource. (2015). *About*. Retrieved from http://www.certisource.org/

CIP (Center for International Policy) & EIA (the Environmental Investigation Agency). (2005). *The Illegal Logging Crisis in Honduras: How U.S. and E.U. Imports of Illegal Honduran Wood Increase Poverty, Fuel Corruption and Devastate Forests and Communities*. Retrieved from http://www. eia-international.org/wp-content/uploads/Honduras-Report-English-low-res.pdf.

Contreras-Hermosilla, A. (2001). *Law Compliance in the Forestry Sector: An Overview*. World Bank, Washington, DC. Retrived from http://siteresources.worldbank.org/EXTFORESTS/Resources/985784217874560960 /Contreras.pdf.

Contreras-Hermosilla, A. (2002). *Policy alternatives to improve law compliance in the forest sector*. Background paper prepared for FAO meeting of experts, Rome

Danielsen, F., Jensen, P. M., Burgess, N. D., Altamirano, R., Alviola, P. A., Andrianandrasana, H., ... & Young, R. (2014). A multicountry assessment of tropical resource monitoring by local communities. *BioScience*, biu001.

Degen, B. (2014). *Application of DNA fingerprints to control tree species and geographic origin of timber* . Thünen-Institute of Forest Genetics, Germany. Retrieved from http://www.globaltimbertrackingnetwork.org/fileadmin/templates/globaltimbertrackingnetwork.org/upload/Regional_Workshop_Americas/Application_of_DNA_fingerprints_to_control_tree_species_and_geographic_origin_of_timber.pdf

Degen, B., & Bouda, H. (2015).Verifying timber in Africa. *ITTO Tropical Forest Update*, 24/1. Retrieved from http://www.forestlegality.org/sites/default/files/verifying_timber.pdf

Deguilloux M.F., Pemonge M.H. & Petit R.J. (2002). Novel perspective in wood certification and forensics: dry wood as a source of DNA. Proceedings of the Royal Society of London Series B. *Biological Science,* 269, 10391046.

Dimitrova, T. (2013, April). *A new tool against illegal logging: tree DNA technology goes mainstream*. Retrieved from http://news.mongabay.com/2013/0422-dimitrova-dna-logging.html

Double Helix. (2011). *Applied Genetics for Forest Conservation and Sustainable Trade*. Retrieved from http://www.unece.lsu.edu/social_responsibility/documents/2013mar/csr13_08.pdf

Double Helix. (2015). *About*. Double Helix Tracking Technologies. Retrieved from http://www.naturesbarcode.com/

Dykstra, D. P., Kuru, G., Taylor, R., Nussbaum, R., Magrath, W. B., & Story, J. (2003).*Technologies for wood tracking: verifying and monitoring the chain of custody and legal compliance in the timber industry*. The World Bank. Retrieved from http://documents.worldbank.org/curated/en/2003/01/2456633/technologies-wood-tracking-verifying-monitoring-chain-custody-legal-compliance-timber-industry

EIA (Environmental Investigation Agency). (2013). *Liquidating the forests: hardwood flooring, organized crime, and the world's last Siberian tigers*. Retrieved from http://issuu.com/eiaglobal/docs/eia_liquidating_report__edits_san?e=7348194/5151956

Encyclopedia Britannica. (2014). *DNA fingerprinting*. Retrieved from http://www.britannica.com/EBchecked/topic/167155/DNA-fingerprinting

Embassy of Costa Rica in Washington DC. (2015). Costa Rica at a glance. Retrieved from http://www.costarica-embassy.org/?q=node/19

FERN, Greenpeace, IFIA (Inter-African Forest Industry Association), Precious Woods, SSNC (Swedish Society for Nature Conservation) & TFT (Tropical Forest Trust). (2008). *Regaining credibility and rebuilding support: Changes the FSC needs to make to ensure it regains and maintains its credibility*. A joint statement. Report, published 30 October 2008. Retrieved from http://www.fern.org/node/4297.

FLEGT Facility. (2015). *What is FLEGT?* Retrieved from: http://www.euflegt.efi.int/about-flegt

FINOFIFO (Fondo Nacional De Financiamiento Forestal) [National Forestry Financing Fund]. (2015). *Pago de Servicios Ambientales [Payment for ecosystem services]*. Retrieved from http://www.fonafifo.go.cr/psa/index.html

Fogarty, D. (2012, August). *Insight: DNA tests tell trees from the wood; curb illegal logging*. Retrieved from http://in.reuters.com/article/2012/08/19/us-timber idINBRE87I09D20120819

FSC (Forest Stewardship Council). (2006). *FSC-STD-40-005 FSC standard for company evaluation of FSC Controlled Wood*. Retrieved from https://us.fsc.org/preview.standard-for-company-evaluation-of-controlled-wood-fsc-std-40-005v2-1en.a-198.pdf

FSC-Watch.(2015). Blog posts. Retrieved from http://fsc-watch.com/

Geist, H.J. & Lambin, E. (2002). Proximate causes and underlying driving forces of tropical deforestation. *Bioscience* 52, pp.143–150

Ghazoul, J., (2001). Barriers to biodiversity conservation in forest certification. *Conservation Biology* 15 (2), pp. 315–317

Gillies, A.C.M., Navarro, C., Lowe, A.J., Newton, A.C., Hernandez, M., Wilson J. & Cornelius, J.P. (1999). Genetic diversity in Mesoamerican populations of mahogany (Swietenia macrophylla), assessed using RAPDs. *Heredity*, 83, pp.722-732

GTTN (Global Timber Tracking Network). (2015). *About and projects*. Retrieved from http://www.globaltimbertrackingnetwork.org/about-us/why-gttn/

Global Witness. (2007). *Cambodia's Family Trees: Illegal Logging and the Stripping of Public Assets by Cambodia's Elite*. Press release. Retrieved from http://www.globalwitness.org/sites/default/files/library/final_english.pdf.

Greenpeace. (2014). *Amazon Logging Crisis*. Retrieved from http://part1.amazoncrisis.org

Greenpeace. (2015). *Protecting Forests*. Retrieved from http://www.greenpeace.org/international/en/campaigns/forests/

Gulbrandsen, L. H. (2008). Accountability arrangements in non-state standards organizations: Instrumental design and imitation. *Organization*, 15(4), pp. 563–583

Halme, K.J, Bodmer, R.E. (2007). Correspondence between scientific and traditional ecological knowledge: Rain forest classification by the non- indigenous ribereños in Peruvian Amazonia. *Biodiversity and Conservation* ,16, pp.1785–1801

Hance, J. (2008, April). *The FSC is the "Enron of forestry" says rainforest activist*. Retrieved from http://news.mongabay.com/2008/0417hance_interview_counsell.html

Happy Planet Index. (2015). *Costa Rica | Happy Planet Index*. Retrieved from http://www.happyplanetindex.org/countries/costa-rica/

Hekkert, M., Negro, S., Heimeriks, G., & Harmsen, R. (2011). *Technological Innovation System Analysis. A manual for analysts*. Utrecht University. Retrieved from http://www. innovation-system. net/wpcontent/uploads/2013/03/UU_02rapport_Technological_Innovation_System_Analysis.

Henley, W. (2013, August). *Tracking timber: could new technology help clean up the supply chain?* Retrieved from http://www.theguardian.com/sustainable-business/tracking-timber-new-technology-supply-chain

Hurtado S. A. (2015). *Wind Energy Development in Mexico - A case study of the potential for local socio-economic benefits in Mareña*. Master Thesis. The International Institute for Industrial Environmental Economics (IIIEE)

ITTO (International Tropical Timber Organization). (2012). *Tracking Sustainability. Review of Electronic and Semi-Electronic Timber Tracking Technologies*. Retrieved from http://www.itto.int/direct/topics/topics_pdf_download/topics_id=3145&no=0&disp=inline

ITTO. (2014). *Projects, Pre-projects*. Retrieved from http://www.itto.int/council_committees/projects/

ITTO. (2014a). *What are illegal logging and trade?* Retrieved from: http://www.itto.int/feature06_01/

Jack, B.K, Kousky, C., Sims, K.R.E. (2008). Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences*, 105, pp. 9465–9470

Jacobsson, S., Johnson, A. (2000). The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research. *Energy Policy*, 28, pp. 625-640.

Lebedys, A. & Li, Y. (2014). *Contribution of the forestry sector to national economies, 1990-2011*. FAO (Food and Agriculture Organization), Forest Finance Working Paper FSFM/ACC/09. Rome.

Lee, M. (2009, September 22). Can we trust the FSC? *The Ecologist*. Retrieved from http://www.theecologist.org/investigations/natural_world/324627/can_we_trust_the_fsc.html

Lindmark, S., Rickne, A. (2005). *Dynamics and Functionality of the Swedish Mobile Internet Innovation System*. Paper presented at the 16th European Regional Conference of The International Telecommunications Society (ITS), Porto.

Lowe, A., & Cross, H. (2012, November). *DNA based methods leave illegal loggers with no place to hide*. Retrieved from http://theconversation.com/dna-based-methods-leave-illegal-loggers-with-no-place-to-hide-8980

Lowe, A. (2012). *DNA Timber Tracking. Opportunities and Challenges*. Retrieved from http://www.globaltimbertrackingnetwork.org/fileadmin/templates/globaltimbertrackingnetwork.org/upload/documents/6_Lowe.pdf

Lumber Liquidators. (2015). *Sustainability: Our Actions*. Retrieved from http://www.lumberliquidators.com/sustainability/our-actions/

Magnussen, J.E., Pikitch, E.K., Clarke, S.C., Nicholson, C., Hoelzel, A.R., Shivji, M. (2007). Genetic tracking of basking shark products in international trade. *Animal Conservation*, 10, pp.199–207.

McDermott, C. L. (2012). Trust, legitimacy and power in forest certification: A case study of the FSC in British Columbia. *Geoforum*, 43(3), pp. 634-644.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Soonhoong, M., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining Supply Chain Management. *Journal of Business Logistics*, 22(2),pp. 1-25.

Michael Höltken, A., Schröder, H., Wischnewski, N., Degen, B., Magel, E., & Fladung, M. (2012). Development of DNA-based methods to identify CITES-protected timber species: a case study in the Meliaceae family. *Holzforschung*, 66(1), pp. 97-104.

MINAE (Ministerio de Ambiente y Energia) [Ministry of Environment and Energy]. (2014*). Lineas de Accion para implementar la Politica de Desarrollo Forestal de Costa Rica 2014-2018 [Lines of Action for Implementing the Policy of Forest Development in Costa Rica 2014-2018]*. Draft.

Navarro, C., Cavers, S., Colpaert, N., Hernandez, G., Breyne, P. & Lowe, A.J. (2005). Chloroplast and total genomic diversity in the endemic Costa Rican tree Lonchocarpus costaricensis (J.D. Smith) Pittier (Papilionaceae). *Silvae Genetica*. ,54, pp.293–300.

Navarro, G., & Thiel, H. (2007, January). *On the Evolution of the Costa Rican Forestry Control System*. Country Case Study. VERIFOR. Retrieved from http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion files/4450.pdf

Navarro, G. A., Vieto, R. J., & Bermúdez, G. (2006). *Costos de Acceso a la Legalidad, Cadenas y Actores de Mercado de la Madera legal e ilegal en Costa Rica [Costs of legality access, supply chains and actors of legal and illegal timber trade in Costa Rica]*. SINAC-FAO. Retrieved from http://www.fao.org/forestry/12925-0876f8fe8d9a597707a654029b82a818a.pdf

Nebel, G., Quevedo, L., Jacobsen, J. B., & Helles, F. (2005). Development and economic significance of forest certification: the case of FSC in Bolivia. *Forest Policy and Economics*, 7(2), pp. 175-186.

Novick, R.R., Dick, C.W., Lemes, M.R., Navarro, C., Caccone, A. & Bermingham, E. (2003). Genetic structure of Mesoamerican populations of Big-leaf mahogany (Swietenia macrophylla) inferred from microsatellite analysis. *Molecular Ecology*, 12, pp. 2885-2893.

Panjer, M., & Greenberg, T. S. (2012). *Justice for forests: Improving criminal justice efforts to combat illegal logging*. World Bank Publications.

Planetopia. (2013). *Report on German TV Sat1 about Paradise Bed*. Retrieved from https://www.youtube.com/watch?v=11Kq4-ZEJf4&feature=youtube_gdata_player(April 7, 2015).

Pillet, N., & Sawyer, M. (2015). EUTR: *Plywood imported from China*. National Measurement and Regulation Office (NMRO), UK. Retrieved from https://www.gov.uk/government/publications/eutr-assessment-of-plywood-imported-from-china

Poynton, S. (July, 2013). Chain of custody nonsense from FSC & PEFC: protecting income streams rather than the world's forests. *Mongabay*. Retrieved March 25, 2015, from http://news.mongabay.com/2013/0710-poynton-fsc-pefc-coc-commentary.html

PROCOMOR (Promotora del Comercio Exterior de Costa Rica) [Promoter of the Foreign Trade in Costa Rica]. (2015). Portal Estadistico de Comercio Exterior [Foreign Trade Statistics Portal]. Retrieved from http://servicios.procomer.go.cr/estadisticas/inicio.aspx

Rodríguez, A. B., & Alfaro, S. U. (2014). *Balanza Comercial y Tendencias de las Exportaciones e Importaciones [Balance of Trade and Import/Export trends]*. ONF (Oficina Nacional Forestal) [National Forestry Office]. Retrieved from http://onfcr.org/article/balanza-comercial-y-tendencias-de-las-exportacione/

Rodríguez, A. B., & Alfaro, S. U. (2014a). *Usos y Aportes de la madera en Costa Rica [Timber use and inputs in Costa Rica]*. ONF (Oficina Nacional Forestal) [National Forestry Office]. Retrieved from http://onfcr.org/media/uploads/documents/uyam_onf_2014_3_af_ultimo.pdf

Roe D., Nelson, F., Sandbrook, C. (eds.) 2009. Community management of natural resources in Africa: Impacts, experiences and future directions. *Natural Resource Issues,* 18. International Institute for Environment and Development, London, UK.

Rudel, T.K. (2005). Changing agents of deforestation: from state initiated to enterprise driven processes, 1970–2000. *Land Use Policy*, 24, pp. 35–41

Schepers, D. H. (2010). Challenges to Legitimacy at the Forest Stewardship Council. *Journal of Business Ethics*, 2, 279.

Scheliha, von S., & Zahnen, J. (2011). *Genetic and isotopic fingerprinting methods-practical tools to verify the declared origin of wood*. GIZ. Retrieved from http://mobil.wwf.de/fileadmin/fmwwf/PublikationenPDF/Fingerprinting_conf_rep_EN.pdf

Schwarzbauer, P. & Rametsteiner, E. (2001). The impact of SFM-certification on forest product markets in Western Europe—an analysis using a forest sector simulation model. *Forest Policy and Economics,* 2, pp. 241–256.

Seidel , F., Fripp, E., & Denty, I. (2012). *Timber Tracking technologies. Review of Electronic and Semi-Electronic Timber Tracking Technologies and Case Studies*. ITTO. Draft Report. Retrieved from http://www.itto.int/files/user/pdf/Meeting%20related%20documents/Timber%20Tracking%20Review.pdf

Sills, J. (2008). *The Need to Cut China's Illegal Timber Imports* . AAAS. Retrieved from http://www.illegallogging.info/sites/default/files/uploads/sciencechinaillegaltimber.pdf

Simmons, R.T., Smith, F.L., Jr. and Georgia, P. (1996). *The tragedy of the commons revisited: politics versus private property*. The Center for Private Conservation, Washington, DC.

SINAC (Sistema Nacional de Áreas de Conservación) [National System of Protected Areas]. (2015). Áreas de Conservación [Conservation areas]. Retrieved from http://www.sinac.go.cr/conozcanos/Paginas/default.aspx

SIREFOR (Sistema de Información de los Recursos Forestales de Costa Rica) [Information system on Costa Rican Forest Resources] (2015). *Publicaciones: Tala ilegal [Pulications. Illegal logging]*. Retrieved from http://www.sirefor.go.cr/?page_id=896

Srdjevic Z. , Bajcetic R. and Srdjevic B. (2012). Identifying the Criteria Set for Multicriteria Decision Making Based on SWOT/PESTLE Analysis: A Case Study of Reconstructing A Water Intake Structure. *Water Resources Management*, 26 (12), pp. 3379-3393

Thang, H.C.. (2008). *Forest law enforcement, governance and trade in Asia—an update. Legality of Traded Timber: The Development Challenges*. FAO, Rome.

The Nature Conservancy. (2015). *Forest Conservation: Responsible Trade*. Retrieved from http://www.nature.org/ourinitiatives/habitats/forests/howwework/combating-illegal-logging-and-advancing-responsible-forest-trade.xml

The REDD Desk. (2015). *REDD in Costa Rica. Readiness overview*. Retrieved from http://theredddesk.org/countries/costa-rica

The University of Adelaide. (2014, March). *"Fingerprinting" trees to stop illegal logging*. Retrieved March from http://www.adelaide.edu.au/news/news68962.html

UNECE & FAO. (2014). *Forest Products. Annual market review 2013-2014*. Geneva Timber and Forest Study Paper 36. Retrieved from http://www.unece.org/forests/fpm/annualmarketreviews.html

Wasser, S.K., Mailand, C., Booth, R., Mutayoba, B., Kisamo, E., Clark, B., Stephens, M. (2007) Using DNA to track the origin of the largest ivory seizure since the 1989 trade ban. *Proceedings of the National Academy of Sciences, USA*, 104, pp.4228–4233.

WPF (World Preservation Foundation). (2014). *Deforestation*. Retrieved from http://www.worldpreservationfoundation.org/topic.php?cat=climateChange&vid=24#.VBbVVfmSyxs

Wright, T., & Carlton, J. (2007, October 30). FSC's 'green' label for wood products gets growing pains. *Wall Street Journal*. Retrieved from http://www.wsj.com/articles/SB119368082115675124

WWF Germany. (2014). *Forensic methods used to verify the declared species and origin of wood*. Retrieved from http://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Forensic-methods-used-to-verify-the-declared-species-and-origin-of-wood-WWF-Germany.pdf.

WWF International & WBSCD (the World Business Council for Sustainable Development). (2015, March 8–10). *Joint Statement for the Forests Dialogue's First International Dialogue on Illegal Logging*. Retrieved from http://oldwww.wbcsd.org/web/projects/forestry/wwf-wbcsd-logging.pdf

WWF (2005). *A Systemic 10 Step Program To Curb Illegal Logging and Improve Law Enforcement in Indonesia*. WWF, Washington, DC. Retrieved from http://assets.panda.org/downloads/fleg10steps11_oct_05.pdf.

WWF. (2014). *EU Government Barometer on Illegal Logging and Trade - 2014: Country Scores*. Retrieved from http://barometer.wwf.org.uk/what_we_do/government_barometer/.

WWF. (2015). *Deforestation.Threats*. Retrieved from https://www.worldwildlife.org/threats/deforestation

WWF-UK. (2014). Failing the Forests. European Illegal Timber Trade. Retrieved from http://www.wwf.se/source.php/1120070/FailingForests.pdf

Zalengera, C., Blanchard, R. E., Eames, P. C., Juma, A. M., Chitawo, M. L., & Gondwe, K. T.(2014). Overview of the Malawi energy situation and A PESTLE analysis for sustainable development of renewable energy. *Renewable and Sustainable Energy Reviews*, *38*, 335–347

Appendix

Annex A: Sample interview questions

Topic 1. Current systems, their limitations
1. What kind of forest governance system is proved to be more effective? (national, international, private, third party certification, etc.)
2. What are the challenges in legality verification of the wood and wood based products imported into EU?
3. How do the governments (e .g. Germany) implement checks on imported timber? (how often, how the document check and sampling is done and other related technical details)
4. What are the approximate annual costs of implementing control and checks on imported timber?
5. What are the main challenges related to FLEGT and VPAs in the context of illegal timber trade?
6. How are these challenges addressed currently?
7. What is the role of timber tracking technologies in current legality verification systems?
8. Does the genetic methods have a potential for wide spread application around the world by governments, certification companies and private businesses?
9. If yes, what are the drivers?
10. If not, what are the barriers (including limitations of the technology)?
11. Can genetic methods be applied in national legality verification system of the timber exporting country (which phases of supply chain?)
12. What kind of measures does the e.g. German government implement for promoting the technology in timber exporting countries?
13. In your opinion, would it be possible for timber exporting countries that apply technology in their national system access premium markets in EU?
Topic 2. Genetic timber tracking methods and their application in international context
1) What is the difference between DNA and other methods such as isotope, infrared, etc.? What can it deliver that others cannot?
2) How does it function?
3) What are the scales of application? At which level?
4) At which phases of CoC it is possible to apply verification the method?
5) What are the current developments in the technology?
6) What are the expected developments in technology? How it would affect the price, as well as costs?
7) What are the limitations (at technology level)?
8) Who are the main actors?

9) What are the drivers for its widespread application?
10) What are the barriers?
11) How long is the preparation period till first kick off the pilot project?
12) What kind of factors should be considered when calculating costs of the project?

Topic 3. Costa Rica, its timber legality verification system and potential of DNA methods

1) How the balance between conservation, reforestation and timber trade is managed?
2) Is there a difference between legal and sustainable timber Costa Rica legislation?
3) How are the forest areas managed? (public, private, etc.)
4) What are the building blocks of forest governance in Costa Rica?
5) What are the factors affecting the timber trade in Costa Rica?
6) What are the revenues from timber trade?
7) What is the high season for timber export?
8) What kind of measures does the legality verification system include?
9) What kind of limitations does the current tracking system have?
10) How the system can be improved?
11) What are the reasons for illegality?
12) What are the species that are traded illegally?
13) Which phases of timber tracking is more vulnerable to illegalities?
14) What kind of damages (numeric) does illegal logging create?
15) What are the costs of current tracking system?
16) How can new technologies affect the market?
17) In your opinion, does genetic method represent a necessary tool for Costa Rica? Or the country needs some other approach?
18) At which level the control over timber trade is necessary? Checking species declarations or origin?
19) What would be the main drivers for the application of technology in Costa Rican system?
20) What would be the main barriers?
21) How would you rate them in terms of urgency and importance?

Annex B: Costs for legality access [37]

Details	Value		Unit
Forest area (ha)	106.2		
Average forest use (ha)	70.4		
Average volume per tree (m3)	4.7		
Average volume per tree (pmt)	1106		
Volume yield of standing wood	65%		
Authorized volume (m3)	1177.1		
Net volume of the permit (m3)	765.1		
Necessary guides	per: 28		
Price per m3 at sawmill	$ 129		
Logging costs m3 (harvest, chopping, dragging, loading, transport)	$ 54		
Total logging costs	$ 41542.3679		
Total income	$ 98663.1255		
Net income	$ 57120.7563		
Property certification (certification, plan, legal status)	$ 31.4974		
Special Power	$ 56.2454		
Contract with forest engineer	$ 63.734		
Technical study	$ 9237.6817		
Timber details			
Common name	**Scientific name**	**# of trees**	**Commercial volume**
Aguacatillo	*Ocotea sp*	1	3.3
Ajillo	*Balizia elegans*	1	4.0
Areno	*Qualea polychroma*	13	54.7
Baco	*Couma macrocarpa*	11	41.2
Botarrama 1	*Vochysia ferruginea*	24	92.1
Botarrama 2	*Vochysia allenii*	31	152.2
Caobilla	*Carapa guianensis*	26	160.7
Carey	*Elaeoluma glabrescens*	3	12.1
Cedro manteco	*Tapirira guianensis*	4	14.4
Cocobolo de San Carlos	*Vatairea lundellii*	11	53.6
Cocora	*Guarea sp*	1	2.8
Corteza	*Tabebuia guayacan*	1	6.6
Cuero sapo	*Licania affinis*	2	6.5
Fruta dorada	*Virola sp*	10	45.2
Gavilán	*Pentaclethra macroloba*	62	246.9
Guabo ron ron	*Inga alba*	1	4.2

[37] for natural forest areas requiring maintenance of Management Plan (sample)

Guácimo blanco	*Goethalsia meiantha*	1	1.8
Guayabo de charco	*Terminalia bucidoides*	1	6.1
Hoja Dorada	*Otoba novogranatensis*	2	7.6
Jícaro	*Lecythis ampla*	2	14.8
Lagarto negro	*Lacmellea panamensis*	1	4.4
Lorito	*Vantanea occidentalis*	4	18.6
Manga larga	*Laetia procera*	1	2.4
Manú negro	*Minquartia guianensis*	2	11.5
Níspero	*Manilkara sp.*	1	6.3
Ojo de gringo	*Abarema macradenia*	1	3.2
Ojoche	*Brosimum sp*	4	14.9
Paleta	*Pterocarpus sp*	4	16.6
Pejibaye	*Maranthes panamensis*	3	10.1
Pilón	*Hyeronima alchorneoides*	1	5.2
Querosén	*Tetragastris panamensis*	13	39.4
Roble coral	*Terminalia amazonia*	2	8.9
Sapotillo	*Pouteria sp*	4	14.9
Tamarindo	*Dialium guianense*	17	67.2
Targuayugo	*Dussia macroprophyllata*	1	2.4
Títor	*Sacoglottis trichogyna*	3	10.7
Zopilote	*Hernandia didymantha*	2	9.5
Total		**272**	**1177.1**

Logging costs		
Activity	**$/ pmt**	**$ / m3**
Harvest and chopping	0.0187	6.7864
Dragging	0.0375	13.5728
Loading	0.0187	6.7864
Transport to sawmill	0.075	27.1455
Total	0.15	54.2961

Source: Adapted from Navarro et al., 2006 and updated by FUNDECOR

Annex C: Sample budget of a project based on DNA barcoding for 13 main species at national level, within 5 years period[38]

National verification system				
1. Development of genetic markers				
	Number of specie			
	1		**13**	
1.1. Trial DNA extraction	$	1,500.00	$	19,500.00
1.2. Population sampling	$	30,000.00	$	15,000.00
1.3. DNA marker development	$	60,000.00	$	780,000.00
1.4. Screening and validation of the database	$	38,500.00	$	8,000.00
Total	**$**	**130,000.00**	**$**	**822,500.00**
3. Implementation of DNA verification				
3.1. Verificaton system development	$	8,000.00		
3.3. Ongoing DNA testing (per test)	$	400.00		
Total	**$**	**8,400.00**		
2. Capacity building, training, salaries, field visits				
	Period (years)			
	1		**5**	
2.1. Stakeholder consulation and work training (training of laboratory workers and SINAC staff	$	10,000.00	$	10,000.00
2.2 Salary (sampling work, per person annually)	$	9,600.00	$	48,000.00
2.3. Salary (laboratory work, per person annually)	$	9,600.00	$	48,000.00
2.4. Salary (added to annual salary of SINAC workers)	$	3,600.00	$	18,000.00
2.5. Continous inspection visits costs per visit/annually)	$	1,200.00	$	6,000.00
2.6. Costs for average number of visits annually per SINAC office (2200)	$	2,640,000.00	$	13,200,000.00
Total	**$**	**2,672,800.00**	**$**	**13,330,000.00**
4. Project coordination and reporting				
	Period (years)			
	1		**5**	
4.1. Lead consultant	$	15,000.00	$	75,000.00
4.2. Project Manager	$	17,000.00	$	85,000.00
4.3. Administrative support & Miscellanous	$	5,000.00	$	25,000.00
Total	**$**	**37,000.00**	**$**	**185,000.00**
Grand Total cost of the project				
	$	**2,848,200.00**	**$**	**14,345,900.00**

Source: Own elaborations based on numbers solicited from Double Helix and Thünen Institute

[38] The cost reduction based on economies of scale applies if only samples of different species are collected at the same time.