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# Timber extraction by cable yarding on flat and wet terrain: a survey of cable y experience

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## Highlights

- Survey of all European cable yarder manufacturers on flat-terrain yarding
- Manufacturers are frequently contacted concerning flat-terrain yarding
- Forest resource inaccessibility, regulatory and environmental considerations are most important motivations
- Lack of clearance, tree stability and installation costs are major challenges
- Mobile, self-anchoring tail spar is considered a chief adaptation
- Cost-competitiveness with ground-based systems cannot be achieved without subsidies
- Increasing environmental awareness and climate change present opportunity to expand flat-terrain cable yarding.

## Abstract

Cable yarding is a general solution for load handling on sites not accessible to ground-based machinery, and is typically associated wi primarily be found on soft or wet soils, most frequently encountered in Central and Northern European countries. Today, changed env unprecedented opportunity to the actual implementation of cable yarding on flat terrain in commercial operations. The study goal wa regarding the use and adaption of cable yarding technology on flat terrain. European manufacturers of cable yarding technology were challenges, adaptation potential, future potential and main hurdles for the expansion of cable yarding on flat terrain. Almost all manu technology solutions, primarily from Germany. Temporal or permanent inaccessibility, regulatory or environmental reasons were the n technology. Installation was considered particularly challenging (clearance, stable anchoring). Potential adaptations included higher tc

extraction and un-guyed yarder-systems. An artificial, highly mobile, self-anchoring tail spar was considered the most useful adaptatic
qualified labour shortage, most manufacturers demonstrated a positive or neutral view concerning the expansion of cable yarding on
be cost-competitive wherever ground-based systems can be employed and cable yarding is not subsidized.

**Keywords**
forest soils; soil compaction; logging equipment; sensitive soils

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## 1 Introduction

Forest management, and especially timber harvesting, can have large impacts on soils due to the eq
disturbance and compaction are the effects of heavy machine traffic during ground-based timber ext
hamper regeneration and cause significant yield losses (Thompson et al. 1998; Grulois 2007; Gebau
amelioration of compacted soils is a long-term process and it is unknown if a complete recovery can
Therefore, methods for removing timber with less damage to both residual vegetation and the soil a
erosion or impassable due to wet and soft soils (Thompson et al. 1998; Worrell et al. 2010). On flat
be encountered in mire, swamp and floodplain forests, as well as the large share of boreal forest gro

The issue of soft and wet terrain has become increasingly urgent, and for two main reasons. Enviror
decreasing the tolerance for soil disturbance (Abbas et al. 2018), and global warming has reduced tl
which has been a solution to traffic on soft and wet terrain up to now (Mohtashami et al. 2017). In t
winter, when the soil was frozen solid and could support heavy loads with minimum damage: today,
required for the soil to freeze, or the cold season is much shorter than before, thus reducing the wir
based harvesting (Goltsev and Lopatin 2013; Daniel et al. 2018). In Finland, Lehtonen et al. (2019)
period of frozen soil conditions will have decreased by one month, and by the end of the century ma
altogether. Such problems are compounded by a third factor: the increasing size and weight of grou
attempt to boost productivity (Nordfjell et al. 2019).

Cable yarding is generally associated with steep terrain; however, it is rather a general solution to lo
traffic (Samset 1985). In the Alps, where most modern yarder developments originated (Bont and H
common steep slope harvesting technique. Today, hundreds of cable-yarding contractors are active i
Austria, Germany, Italy and Switzerland (Spinelli et al. 2013).

The gentler mode of operation with regard to soils is considered cable yarding's outstanding advanta
and wet sites (LeDoux and Baumgras 1990; Stokes and Schilling 1997; Thompson et al. 1998; Ower

2016) and a frequent reason for selecting this extraction technology (Biernath 2009; Biernath 2011; Hofmann 2016; Kirsten 2019). As no heavy machines traverse the terrain, soil impacts are minimize Thompson 1996). Thompson et al. (1998) compared site disturbance after cable yarding of tree leng and grapple skidding of tree lengths after felling with a tracked feller-buncher and motor-manual pr Minnesota. Cable yarding disturbed a much smaller share (9%) of the total area than the forwarder Similar results were reported for two case studies in Germany's northeastern province of Mecklenbu The lower degree of disturbance is explained by the way loads are extracted in cable yarding: partia they apply little pressure to the soil. Compared to skidding by tractors, this reduces the amount of d Thompson et al. 1998; Owende et al. 2002). Causes for soil disturbance and compaction are limited operations, and to occasional dragging of the load during extraction (Thompson et al. 1998). In the segments of the yarding corridor lacking clearance, which can be avoided by intermediate supports ( The gentle work mode enables extraction in watershed protection areas, that are not accessible to c environmental reasons (Brown and Kellogg 1996).

Advantages of cable yarding include the temporal and spatial extension of the harvesting season on frozen (Thompson et al. 1998; Kirsten 2019). In this respect, Silande (1999) reported that seasonal crew's work period to 6 to 7 months a year, resulting in low utilization rates and reduced annual pro suggested to extend cable yarding operations to sensitive soils in the plains during wintertime; a ste taken already (Biernath 2011).

However, cable yarding on flat and wet terrain presents specific challenges. Firstly, the carriage can installation of a haul-back line becomes inevitable (Thompson et al. 1998), entailing additional insta employing self-propelled carriages, which require neither main nor haul-back line. Further, carriage s (Thompson et al. 1998), which results in lower productivity. Secondly, cable yarding requires tail hol on yarding distance – intermediate supports. Trees are the preferable option for these elements (Ma not available, as trees in wet areas are prone to shallow rooting and thus easy uprooting (Thompson

Approaches to tackle these challenges include pre-rigging corridors to reduce unproductive time dur artificial and/or mobile tail holds/spars to compensate for the lack of natural ones (Fraser and Robin TU Dresden 2016) and increasing tower height and skyline tension to allow for longer single spans ( present means of stability (Owende et al. 2002), as in case of the Koller KX304 and KX800E (Koller 2 Herzog's Grizzly 400 (Herzog 2019) machines.

Introduction of cable yarding to flat and wet sites is not a new idea and it has been used intermitte Lidgerwood 1919; Ziemer 1980; Koten and Peters 1985; Meek 1997). Yarding equipment was alrea 1900s to move logs to the railroad line (Williams 1908; Lidgerwood 1919). Today, changed environm unprecedented opportunity to a more wide-spread implementation of flat-terrain cable yarding in co professional journals suggest this practice has gained some traction in Central Europe (Biernath 200

2015; Biernath 2016; Kirsten 2019), and might soon expand to Eastern Europe and Fenno-Scandia, outperformed by more productive and less costly ground-based systems.

Therefore, the goal of this study was to collect cable yarder manufacturer´s experience regarding th technology on flat terrain. For their role at the top of the technology supply chain, manufacturers ar what conditions their equipment is used (or can be used) on flat terrain. Obviously, they will also kn received) specific adaptations for optimum performance in flat terrain. To this end, the authors inter cable yarding technology, with just three exceptions. Three sub-goals were formulated: 1) to investi customers working on flat terrain, 2) to explore their opinion concerning the particular challenges of they see adaption potential and 3) to learn about their view of cable yarding's future potential on fla expanding its use under these conditions.

# 2 Material and methods

## 2.1 Sample

The survey was conducted between February and April 2019, and it was geographically limited to m with headquarters in a European country. Manufacturers qualified if their product range included at l designed for the installation of a cableway system. Simple winches designed for dragging loads on t were not considered eligible. Manufacturers offering only carriages were excluded from the survey.

## 2.2 Interviews

The authors developed a simple and concise interview form, including 13 questions ordered within f questions could be answered by either yes or no and were followed by an open sub-question in case sub-questions was to further elaborate on the respective topics. General comments and opinions we categorization and analysis. Altogether, 18 manufacturers were contacted via e-mail or telephone an participate in the survey. To the authors knowledge, this number is equivalent to a full inventory unc

Table 1. Interview form displaying thematic groups, question ID, question content and category. groups and question level (letters for the thematic group, one digit numbers for questions, doubl questions).

| Thematic group | ID | Question/Sub-question |
|---|---|---|
| Company figures | A1 | Company establishment year |
| | A2 | Number of employees (SME classification; European Commission, 2017 ) |
| | A3 | Market size (number of countries) |
| | A4 | Number of produced yarding equipment per year |
| Customer experience | B1 | Has your company ever received requests from customers concerning cable yarding equipment for use in flat and/or wet terrain conditions? |
| | B11 | If yes, from which country/countries? |
| | B2 | Does your company offer cable yarding equipment that has been specifically adapted to flat and/or wet terrain conditions? |

| | | |
|---|---|---|
| | B21 | If yes, what have these adaptions been? |
| | B3 | Are you aware of customers that are using your equipment for cable yarding operations on flat and/or wet terrain? |
| | B31 | If yes, do you know what their primary motivations to use this system are (in order of perceived priority)? |
| Specific challenges and adaption potential | C1 | From your point of view, what are the specific challenges of cable yarding on flat and/or wet terrain concerning installation, with particular respect to anchors, intermediate supports, tail hold trees and clearance? |
| | C2 | From your point of view, what are the specific challenges of cable yarding on flat and/or wet terrain concerning operation, with particular respect to productivity and cost? |
| | C3 | From your point of view, what are the specific challenges of cable yarding on flat and/or wet terrain concerning other areas? |
| | C4 | Do you think cable yarding equipment could be specifically adapted to better suit for flat and/or wet terrain conditions? |
| | C41 | If yes, what would these adaptions be? |
| Future potential | D1 | Do you think that the demand for cable yarding operations on flat terrain will increase as a result of altered operation conditions (climate change and society's environmental awareness)? |
| | D2 | What do you think are the main hurdles to a further expansion of cable yarding in flat terrain? |

### 2.3 Analysis

Interview notes were immediately entered into Microsoft Word as individual files, corresponding to e interview files were then read by the same lead researchers, who looked for commonly voiced opini under the same conceptual category. This categorized data was entered into a single master data ba the goal statement, the study's primary aim was to collect cable yarder manufacturer´s experience r yarding technology on flat terrain. For this reason and due to the type of collected data, analysis foc further statistical analysis was conducted.

## 3 Results

### 3.1 Company figures

The final database contained 15 observations, because three out of the 18 eligible manufacturers de survey. This corresponds to a positive response rate above 80%. While originating from six different concentrated in the alpine region (13 in Austria, Italy, Slovenia and Switzerland). The other two wer Europe (Czech Republic and Norway).

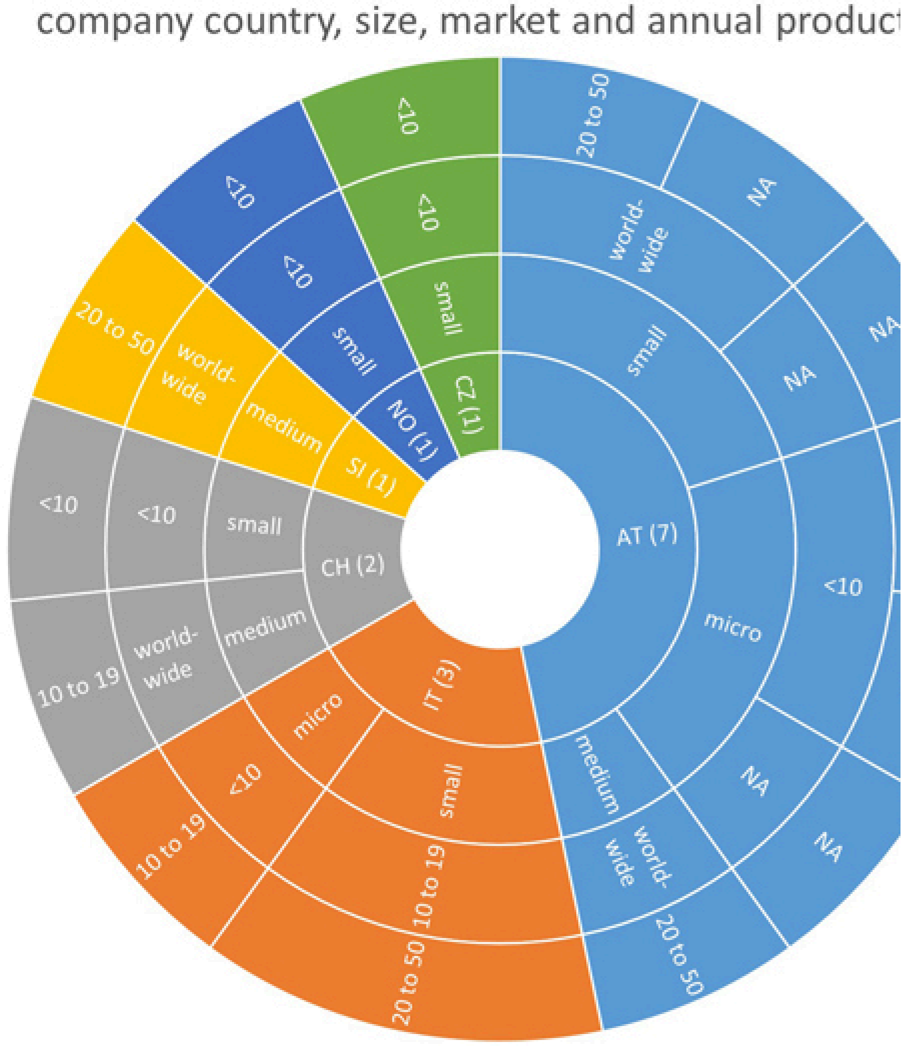


Fig. 1. Company country and number of companies per country in bracket (innermost circle; AT = Austria, IT = Italy, CH = S
Republic), size (second circle from centre; according to SME classification of the European Commission (2017)), market si
circle from the centre) and average annual number of produced pieces of cable yarding equipment (outermost circle). Wh
either not be provided by the companies or they were not willing to share

The production of cable yarding equipment is mostly with micro (27%) and small (53%) enterprises belonged to the medium enterprise category. However, the number of employees working for a man output of cable yarding equipment, as most manufacturers have a wider portfolio of products – and

Five of the companies declared to operate "worldwide" (20 or more countries), while market size wa them, with two companies selling in 10 to 19 countries, and six companies selling in less than 10 co answer this question.

Five of the respondents stated that they produced 20 to 50 pieces of cable yarding equipment (towe Two reported a production between 10 and 19 pieces, while further four declared that they produce companies did not want to answer this question.

### 3.2 Customer experience

All but one company declared they had received customer requests concerning cable yarding on flat company specified that the requests concerned flat but not wet terrain, while all the others indicatec subject of the requests. Only one respondent stated that they've never been contacted concerning s that most requests came from Germany (named 9 times out of 29 mentioned countries) (Fig. 2). Ru while Austria, France and Belarus received two nominations each. One nomination each was recorde Romania, Spain and Switzerland.

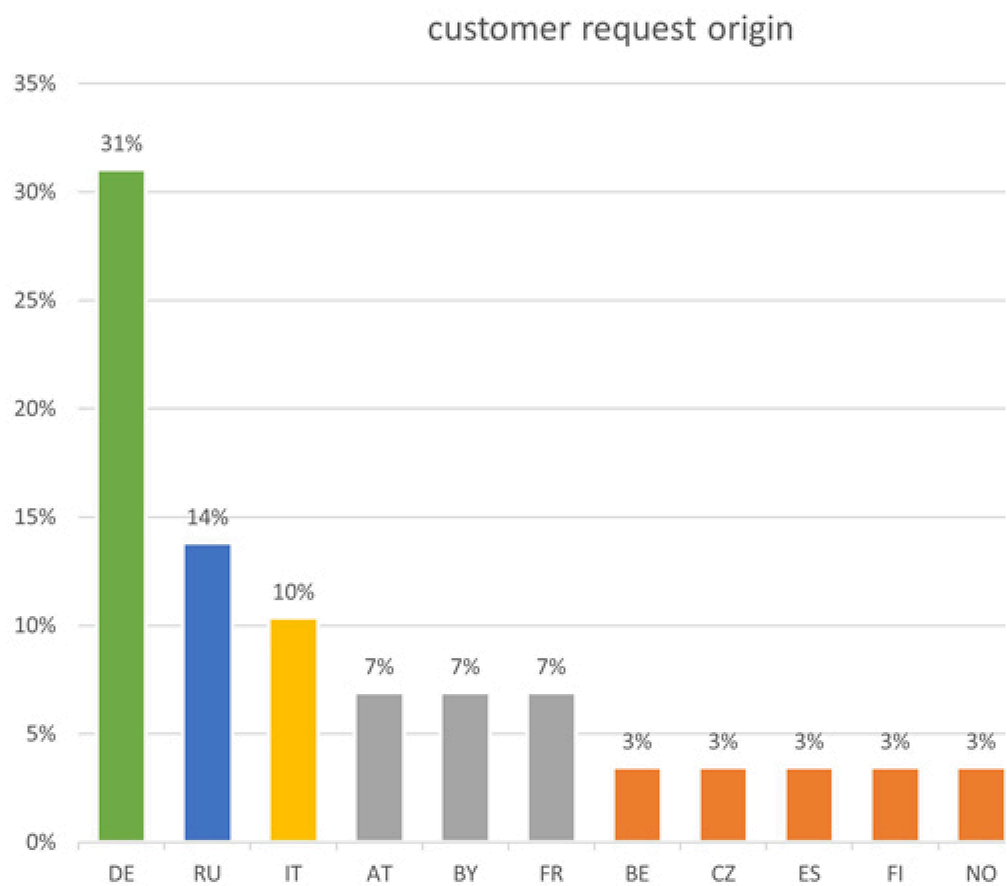


Fig. 2. Origin of customer requests for flat terrain cable yarding technology by country (DE = Germany, RU = Russia, IT = Belgium, CZ = Czech Republic, ES = Spain, FI = Finland, NO = Norway, PL = Poland,

Eleven of the companies stated that they had already adapted their machinery to flat and wet terrai adapt it based on customer demand. Four companies stated that they did not offer specific adaptati

Three major groups of adaptations were identified from a total of 13 mentioned ones. The first grou machine (23%) to improve the mobility of the winch assembly on difficult terrain, such as the use o locomotion devices (tracked base machines). A second group (54%) covered adaptations of the win independent of slope and to increase line lift. These included three-drum-systems (skyline, mainline (endless loop) systems for sled winches (winches mounted on a sled-like structure and generally use extended towers, artificial supports, self-propelled carriages, twin-carriage systems (Studier and Bin extraction of whole trees and longer chokers for pre-concentrated loads. Finally, a third group of ans supporting, excavator-based yarder concept as a solution to overcome the limitations in anchor avail wet terrain.

Ten of the companies were aware of customers employing their equipment on flat and wet terrain ir reported of non-forestry customers using their machines in flat terrain for construction work. One pc both sectors. Only two declared that they were not aware of any customer activities in flat-terrain o

Out of a total of 22, permanent (wet or rock strewn terrain) or temporarily (shortened frost periods) machinery was the most frequently (45%) named motivation for employing cable yarding on flat anc second most important group of reasons (32%). This category included restrictions to ground-basec conservation or watershed protection measures, as well as governmental interventions, i.e. subsidie: achieved by cable yarding. The smallest group (23%) reported that the implementation of cable yar environmental considerations on otherwise accessible areas.

### 3.3 Specific challenges and adaptation potential

Flat-terrain challenges were collected and analyzed separately for installation and operation. Concer indicated that limited terrain clearance was the most important challenge when deploying cable yarc Half of these further stated that this lack of clearance results in shortened span lengths (75 m to 20 and costly installation of a higher number of intermediate supports than would be required on a ste challenge included restriction to single spans and increased skyline tension. However, at least one cc tension has drawbacks in the form of reduced payload capacity, higher strain on the anchors and an slip out of the support jacks. A further challenge mentioned by seven manufacturers was the absenc tailhold and intermediate supports. Respondents further indicated that the lack of suitable anchors i: stands (smaller trees, hindrance by the crown), after forest damage (trees have been blown down) a agricultural land (permanent absence of trees) – all situations being especially frequent when operat and on an opposite note, some respondents pointed out that the installation of artificial anchors mig more space and machine accessibility is better than generally found in steep terrain. That would be order to bury deadman anchors or to act as an anchor itself. Concern about challenges encountered than for those related to installation, and it was difficult to identify a clear pattern or focus. Three re during operation on flat and wet terrain may be close to (or slightly above) that achieved for downh productivity obtained for uphill yarding. Experience of the yarding crew, efficient pre-concentration a corridor were considered important success factors. If mentioned at all, high operating costs were li or the purchase price of dedicated flat-terrain cable yarding equipment.

All but two companies stated that they saw potential for the specific adaptation of cable yarding equ Proposed solutions were classified into three groups: better use of already existing technology, actu technology and new, purpose-built devices (Fig. 3).

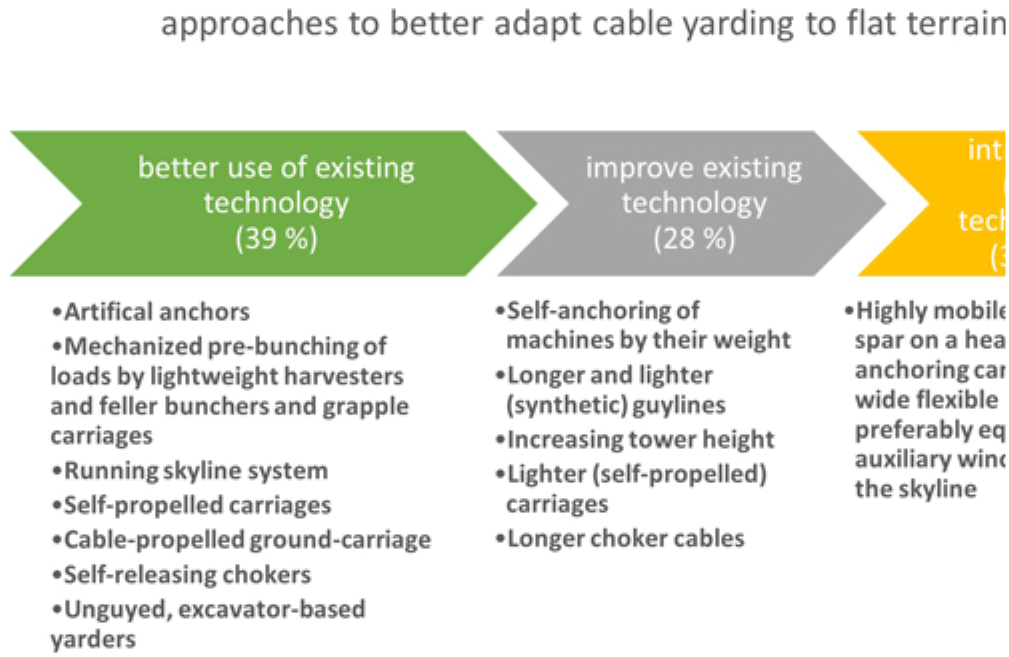


Fig. 3. Major groups of approaches to better adapt cable yarding to flat terrain and examples of

Out of a total of 18, seven (39%) were classified as new ways of using already existing technologica such as deadman or machine anchors was advocated by several respondents as a solution to overcc offering self-supporting, excavator-based yarder technology stated that this system is superior to otl capital costs, faster and easier installation and lower workforce requirements. A further approach to was to employ a wheeled platform ("ground-carriage") similar to a forwarders bunk, which operates a "skyline" that is suspended between the harvester, which directly cuts or lifts the logs onto the bu equipped with a crane for unloading (Konrad 2020). One respondent considered tail spar stability to systems were employed, as they would exert less strain on the tail spar. Pre-bunching of loads befor yarding productivity in general. To achieve this effect, respondents favoured mechanized felling and should be done by light tracked harvesters or feller-bunchers.

One respondent pointed out that the advantage of bunched loads should be exploited further by em propelled carriages on flat terrain was considered to offer increased efficiency at low capital cost. Af designed for such conditions from the very start. Furthermore, a more widespread adoption of self-r respondent, while another demonstrated a very hands-on attitude by suggesting waterproof footwea

Increasing the height of the tower was the most frequently named adaptation among adaptations tc 28% of the mentioned solutions. One respondent argued that longer guylines would allow a more fa less upward pulling force on the trees (or stumps) used as anchors, while another advocated genera worker strain during installation. In order to improve the mobility of lattice mast type intermediate s sled-like platforms was suggested. Self-anchoring of cable yarders by their own weight was seen as challenge. By reducing the weight of carriages, their payload could be increased, particularly that of quite cumbersome structures up to now. Finally, longer choker cables were suggested to be able to

The third group comprised of variations of one main innovation, which was a mobile artificial tail spa challenges related to lack of clearance and stability at once. Firstly, the tail hold should be of a heigh eliminating the need for intermediate supports and thus reducing set up time. The respondents refe height", but did not specify what this might mean in terms of meters. However, they made it clear th heights and that this approach would require improvements in anchoring. Placing the spar on a heav merely the machine's own weight was considered the preferable solution. A tracked base machine w operation mode would be to move parallel to the cable yarder from corridor to corridor on connectin the machine should be equipped with an auxiliary winch to pull out the skyline. One respondent con tracks (swamp tracks) as the optimal solution, because this vehicle would be able to free itself if stu

### 3.4 Future potential and main hurdles

Most survey respondents demonstrated either a positive (47%) or neutral (33%) attitude towards th yarding on flat and wet terrain may increase in the near future. Only a fifth of the respondents were remain a (stable) niche business. Increased environmental awareness of both the public and forest i as forest managers and harvesting contractors are expected to prevent extensive soil disturbance. F owners have already imposed restrictions on extraction technology, often in the form of prohibiting t Finally, decreased accessibility of forest resources as a result of reduced soil bearing capacity due to to access forest resources in difficult terrain to fulfill raw material demand was identified as a major flat terrain. Neutral respondents were either simply inconclusive or had a differentiated view with re countries or the availability of subsidies.

About two thirds of the named obstacles to a further expansion of cable yarding on flat and wet terr operating costs due to complicated installation and especially in comparison to ground-based alterna concern: they stated that successful expansion may only be possible through legal restrictions on gr through subsidies in support of yarding that may offset the higher operating costs. Two manufacture equipment might be too expensive to permit widespread adoption, especially among farmers. A sing inefficiency and high cost due to a lack of bunching, given that machine access constraints would fa mechanized felling and the former cannot achieve a good pre-bunching of felled trees. If pre-bunchi a grapple carriage to take advantage of the bunched loads. A further respondent mentioned that cal compared to harvester and forwarder, as long as it cannot be operated safely at night.

Workforce-related hurdles comprise the second group of obstacles. All respondents in this group co qualified and motivated personnel experienced by the forest sector in general, and by cable yarding terrain was considered the least attractive: even if moving might be less tiresome on flat terrain tha and muddy terrain was considered particularly unattractive. One participant indicated the constructi capable of offering easier jobs for a qualified workforce. Several respondents reported that labour s anticipated machine purchases. In the opinion of one respondent, this issue can only be overcome b allow operating without workers in the field.

# 4 Discussion and conclusions

## 4.1 Limitations of the study

First of all, this study represents the views and opinions of the interviewed company representatives experience, area of operation and own portfolio of products. On the other hand, most questions wer checked for plausibility and consistency, which excluded gross distortions. Of course, the geographic representative of European yarding technology only: different yarding concepts developed in other a and limitations when it comes to operation in flat terrain and if so, these additional elements are not specific experience of European manufacturers. That is especially relevant when one considers that yarding come from North America (LeDoux and Baumgras 1990; Stokes and Schilling 1997; Thomps difference in space and time between those earlier studies and the current survey offers an opportu issues and the proposed solutions. The discussion that follows seems to deny any major progress in principles are concerned.

Second, some degree of subjectivity was unavoidable when the researchers categorized the open qu attributed some answers to different categories than it was done here by the authors of this paper. I categories with the utmost care and after extensive discussion, whenever attribution was doubtful. F taken by the same researcher, in order to guarantee the internal consistency of the dataset.

Third and final, the dataset was unbalanced concerning manufacturer characteristics, as expressed b annual production of cable yarding equipment. As the sample size is equivalent to a full inventory, th considered representative for the European manufacturers of cable yarding equipment.

## 4.2 Technology

Broadly speaking, the survey indicates that: a) almost all manufacturers have received requests for f and b) that almost all have adequate solutions available within their own product range. However, th all-terrain yarding products, rather than individual items specifically designed for flat-terrain yarding. statement, e.g. self-propelled artificial intermediate supports developed by at least two manufacture for improving off-road mobility and machine stability (Sündermann et al. 2013). This indicates that e enough to allow cable yarding over a wide range of different site conditions, including flat and wet t conclusion that it is a true all-terrain load-handling solution.

## 4.3 Market

Again, almost all manufacturers know of customers who have used or are regularly using their yarde doing so – when they are known – are not exclusively related to poor bearing capacity and/or soil pı include excessive roughness (i.e. rocks) and/or the need to avoid trail blazing. Yarding on flat terrair Germany is by far the most represented. This matches the extensive coverage found in the German 2009; Biernath 2011; Schröter 2011; Haberl 2015; Biernath 2016; Kirsten 2019), research reports (F Hoffmann 2016; TU Dresden 2016; Teschner 2016) and thematic events, such as the KWF thematic 2013; Sündermann et al. 2013). The German prevalence may be explained by an ideal combination one hand, soft and wet terrain is well represented in Germany, especially in the Northern part. That countries located further south, where there is not much flat terrain available to forestry and/or whe wetlands. These are the countries where cable yarding is generally associated with steep terrain. Co Alpine conditions in the South and more Nordic wetland conditions in the North, and that favours the the same time, a relative wealth and a generally favourable wood market (despite the ups and dowr additional margins for environmental compliance – that is, reinvesting some of the profits into enviro a strong tradition for environmental awareness, which has generated a very strong emphasis on red any rate, all respondents indicate that the implementation of cable yarding technology in flat terrain Germany included. What is more, the majority of respondents believe that flat- terrain yarding will s even if the changing climate and societal demands may cause some limited expansion.

### 4.4 Challenges and opportunities

There is a general agreement for what concerns the main challenges: a higher harvesting cost than equipment (financial challenge), a clearance problem due to the unfavourable terrain profile (technic qualified labor (workforce challenge).

Cost for ground-based extraction with forwarders in Europe vary between studies and with country, treatment (thinning, regeneration felling). Figures normally vary from 4 to 10 € $m^{-3}$ (Enache et al. 2 2018). Extraction by cable yarding is considerably more expensive, and can exceed 20 € $m^{-3}$ (Enach complete harvesting cost – i.e. felling, processing and extraction – figures range from 8 to 16 € $m^{-3}$ Europe (LUKE 2019), and over 40 € $m^{-3}$ for cable-based harvesting in the Alps (Spinelli et al. 2015). the cost of ground-based and cable-based harvesting indicates that the average contract rate is 12 € € $m^{-3}$ for cable-based operations (Spinelli et al. 2017). Considering the large disparity in unit cost be extraction, it is highly unlikely that cable yarding will ever be competitive on flat terrain, even if all a manufacturers were applied. However, this statement may only be valid for areas where ground-bas degrees of soil disturbance.

On the contrary, the clearance hurdle is straightforward, and refers to the disadvantages suffered wl terrain, as opposed to steep terrain. In that regard, respondents agree on the challenge and on the increasing the height of the tower and the number of supports.

Finally, the shortage of qualified labor is a general challenge experienced by the forest sector worldw three main reasons for labour shortage in forestry listed in a recent study from New Zealand (MPI 2( context too. They are: (1) inability to attract new entrants in the business, (2) unattractive employm location etc.) and (3) experienced staff leaving the industry. Competition with other industries ranke Europe's Forest 2015 report (FOREST EUROPE 2015) indicates that around 30% of all people emplo years old, and attracting young people to study and work in the forest sector is considered a main c yarding especially hard because of the larger labour requirements of cable technology compared to operators must station on the cutover, exposed to the elements, for hooking the loads (Stampfer et

Respondents offered many different and insightful suggestions to make flat-terrain yarding more effi new ways of employing existing technology may simply reflect a lack of imagination in deploying tec radio controlled chokers). Others, such as reducing tail spar stress by employing a running skyline s conditions only. Actually, this system has already been successfully tested by Lisland (1996) in Norw a way to more efficiently pre-bunch loads and thus boost yarder productivity and offset installation-r Lisland 1996; Visser and Stampfer 1998; Spinelli et al. 2019), especially in combination with a grapp specifically asked for light tracked harvesters or feller-buncher to pre-bunch loads. Considering the t size, the use of low-mass machinery would implicate a shorter crane reach and necessitate a tighter corridors would be required and less volume would be harvested per corridor. More corridors would yarder and probably a larger area would be impacted by traffic. Therefore, the respondent's motivat from soil bearing capacity considerations and from the assumption that lighter machines correspond various implications. However, this problem could be overcome by the cutting-strip method, where s 5 to 7 m travel on a cutting strip inside the stand on so-called "ghost trails" and pile the processed l (Ovaskainen et al. 2006). On the other hand, corridor spacing could be increased beyond double the felling trees by chainsaw towards the corridor in order to make them accessible to the harvester for

Taking more machines on site could speed up building of artificial anchors – or the machines could b installation less dependent on tree anchors and allowing the exact calculation of anchor resistance ( anchoring of machines has successfully been realized, usually for excavator-based machines (Herzog height would improve cable yarding efficiency on flat terrain by eliminating or reducing the need for respondents indicated that this has been done before on customer request. Canopy height is often r Depending on tree species, site conditions and stand age, this would range between 10 m and 35 m double the height of the largest European tower at the moment (17 m; Wassermann 2019). The mo self-anchoring, canopy-height tail spar. It is envisioned to speed up installation by eliminating the ne up a tree tail spar. Combined with a self-anchoring cable yarder, this would eliminate any anchoring would have to be large and heavy, as demonstrated by a solution from Canada (Teleforest 2019), wl masts support the skyline. Summing up, the majority of the proposed innovations aimed to simplify demand for natural anchors, intermediate supports and tail spars. Innovations to improve operationa bunching and improved loading and unloading practises. Finally, the Authors believe that the genera would make it possible to integrate flat-terrain and steep-terrain contracts within a company's work utilization. Most mountain operations are paused during winter due to heavy snow conditions, and tl (Silande 1999). Coming down to the lowlands for some flat-terrain yarding could then represent a us shut down (Grulois 2007).

### 4.5 Future scenarios

None of the respondents expects a rapid general expansion of flat-terrain cable yarding in the short this practice will gain ground over time. However, several external indicators may justify more optim high in many countries, and it keeps growing almost everywhere. Furthermore, the duration of the f every year in most regions of the globe (e.g. in Finland; Lehtonen et al. 2019), which makes it incre solutions. Manufacturers of ground-based solutions seek to lower the impact of machine traffic on sc machine and soil through adapting tyre pressure, hydro-pneumatic suspension (e.g. the Forwarder2( employing wider or longer tracks (Ala-Ilomäki et al. 2011), as well as by reinforcing strip roads with routing solutions to bypass areas of very low bearing capacity. Recent developments for soft terrain forwarders or a forwarder with a rubber-tracked undercarriage (OnTrack project, OnTrack 2017). Th ground-based solutions will continue to be the most efficient means to extract timber on flat terrain, balance the decline in terrain traversability. For cable yarding, some of the suggested adaptations m competitiveness on flat terrain in the near future: Acuna et al. (2011) found that bunching of trees i Raymond (2017) showed that radio-controlled grapple carriages equipped with video cameras could on slope unnecessary, while increasing productivity by 35%. However, even if all adaptions were imp likely to be restricted to areas where ground-based systems are undesirable for excessive soil disturl desire for cable yarding is expressed by subsidies.

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