Task 5

5.1.1

Polymers with Young's modulus value of at least 0.8 GPa were compared in material property chart in figure 1. Granta Edupack, level 2 database was used for comparison. Based on figure 1, polylactide (PLA) and starch based thermoplastics (TPS) require the least energy as they are being produced from their raw materials into a form that is suitable for the next manufacturing step. In table 1, the embodied energy during primary production, for PLA and TPS are compared to PEEK to see the difference. From all the polymers in Granta Edupack level 2 database, PEEK requires the most energy during its primary production.

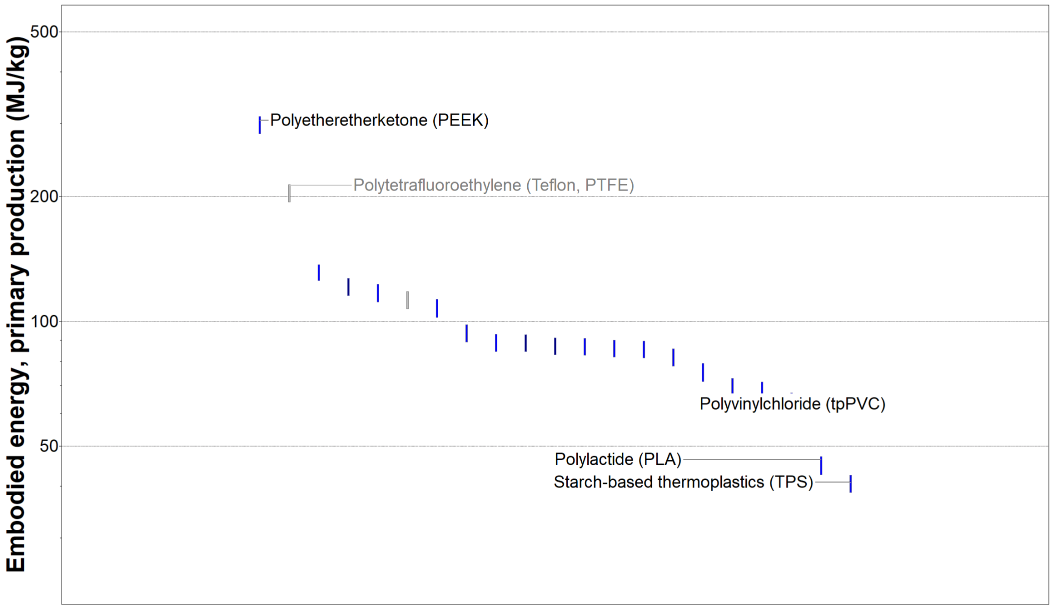

Figure 1: The embodied energy during primary production of polymers. The polymers with Young's module below 0.8 *GPa* are grey in the chart. Granta Edupack,level 2 database.

Table 1: Embodied energy during the primary production of TPS, PLA and PEEK.

Polymer	Embodied energy during the primary production $\frac{MJ}{kg}$
TPS	38.6–42.6
PLA	42.5–47.2
PEEK	283–312

5.1.2

The beam strength and CO_2 emissions of all the materials in level 2 database were compared in figure 2. Material index $M = \frac{\sigma^{1.5}}{\rho}$ was used to rank the materials. This ranking shows that natural materials like bamboo and hardwood have a good Yield strength and leave a relatively small CO_2 footprint during their primary production. Limestone was ranked as the best material with material index M. However, this comparison only considers CO_2 footprint during the primary production of the materials. Additional CO_2 might be released during next production steps which will likely increase the actual CO_2 footprint of a object made out of limestone more when compared to for example woods.

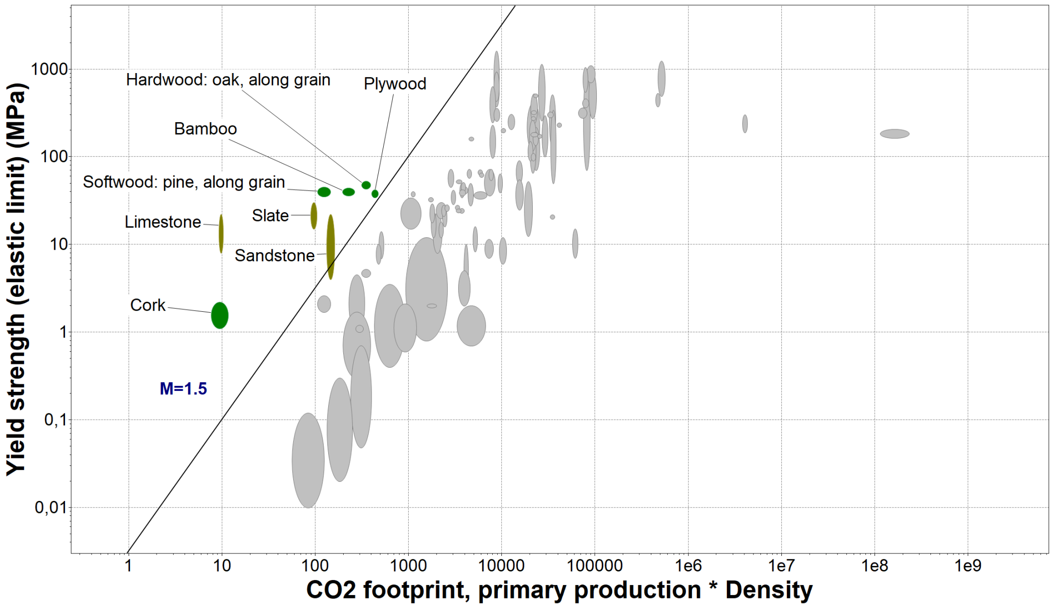

Figure 2: Yield strength vs. CO2 emissions of primary production. Granta Edupack,level 2 database.

In figure 3, only materials that can be recycled are considered. This eliminates all of the materials that were ranked well in previous chart (in figure 2). Now the best ranked materials are steels, polyhydroxyalkanoates and the combination of paper and cardboard.

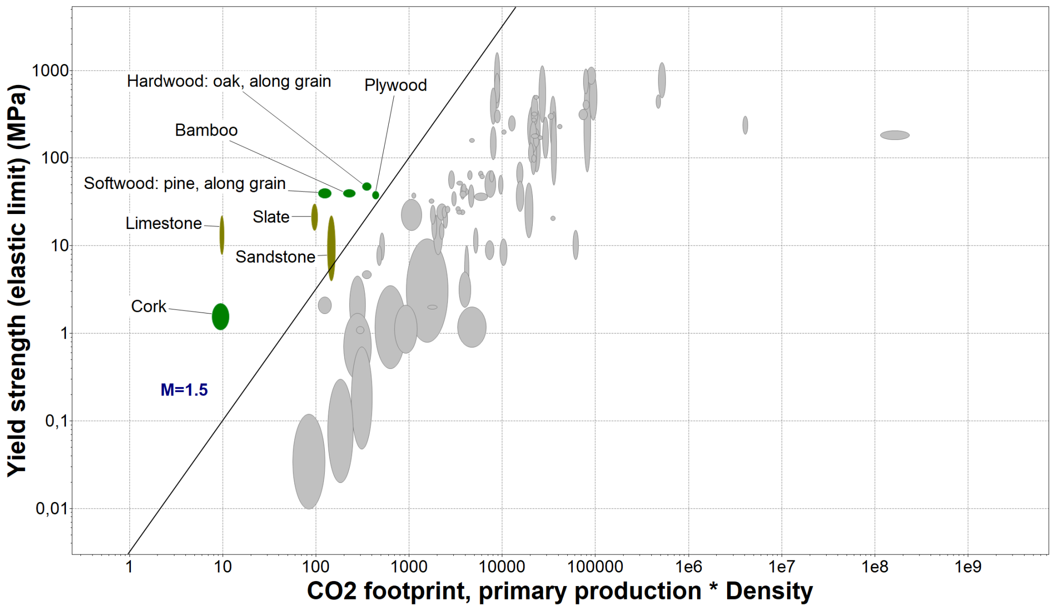

Figure 3: Yield strength vs. CO2 emissions of primary production, only recyclable materials. Granta Edupack,level 2 database.

5.1.3–4

To compare the total energy consumption and CO_2 footprint of a wind turbine blade made either from CFRP, GRP or aluminum, Granta Edupack EcoAudit was used. For 2 600km transportation from Rotterdam to Oulu, it was estimated that a semi-truck with EU 6 vehicle standard weighing more than 32tons, was used to transport the 30 m long wind turbine blade. According to the EcoAudit reports shown in figure 4, it was found that most energy is consumed and CO_2 is released during the material processing of a wind turbine blade during its life cycle. Based on these reports, if the end-of-life recycling scenarios are not considered, GR, the traditional material used in wind turbine blades, is the obvious choice from ecological point of view because. During GRP processing, the least energy is consumed and CO_2 is released.

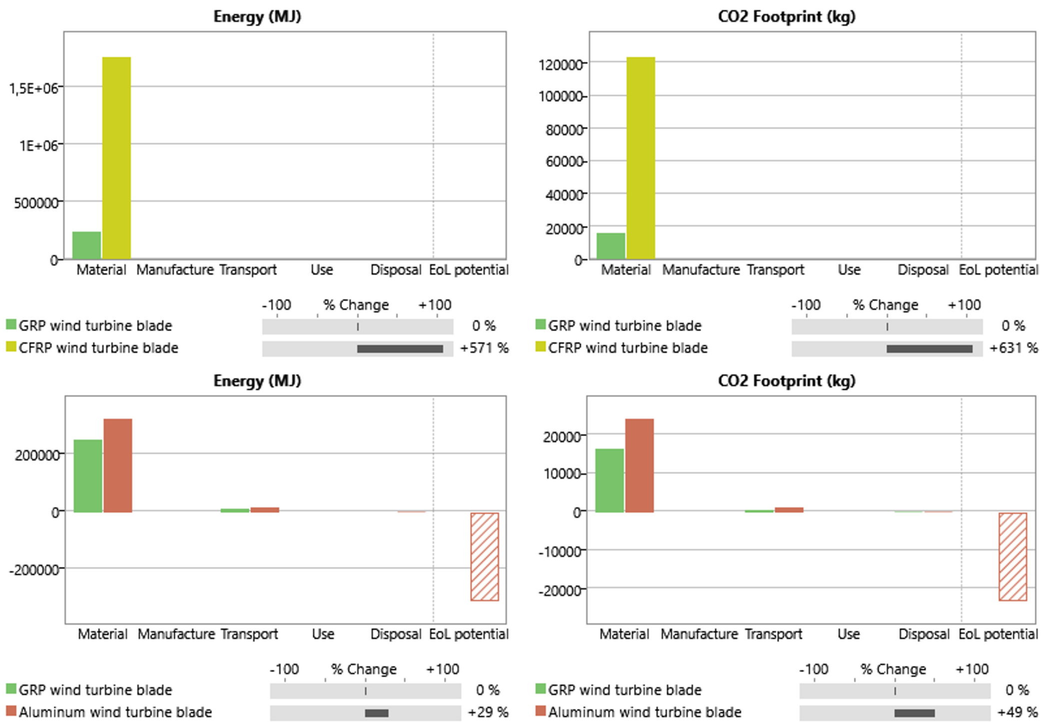

Figure 4: Energy consumption and CO_2 footprint report of CFRP, GRP and aluminum wind turbine blades, made with Granta Edupack, level 2 database.

The issue with CFRP and GRP is that their end-of-life scenarios are limited. Most useful end-of-life scenario for these fibre reinforced epoxy materials is repurposing them as a construction material, but mostly these materials and up becoming landfill. Here is where aluminum differs in its favor due to its great recyclability. Based on the reports in figure 4, if all the aluminum used in wind turbine blades would be recycled, the overall energy consumption and CO_2 footprint of the wind turbine blade would decrease so much, that it would become more sustainable to use aluminum than GRP.

5.2.2

Adhesives are usually easy way to connect pieces and do not require a lot from the design of the noined ppieces. However, joining processes that are using adhesives are prone to degradation over time, they also usually require lot of surface preparation and do not provide as rigid connections as some of the other joining methods. Fasteners provide a more rigid connection but require a more complex design.

Additive manufacturing is an interesting shaping process. It offers a quick way to do prototyping and get a physical product very quickly from designing it. Very complex shapes can be achieved by using additive manufacturing. Machining is the other way opposite of additive manufacturing. With machining more tougher materials like metals and concrete can be shaped. Machining tends to consume lot of energy and requires more skills and substance knowledge than typical additive manufacturing techniques. Sewing on the other hand is completely another way of shaping materials. It is typical way of shaping kevlar, which known from its rigid and tough properties. Sewing is labor intensive processing method, but the product is usually high quality if it has been sewed.

Painting is a way to enhance both visual and technical properties of the materials. Painting is usually very easy and cheap process, but knowledge is required to make sure that the chemical in paints do not corrode the material and do not leak into the nature. Painting also requires a lot of surface preparation and thus, depending on the complexity of the painted surface,tends to be labor intensive. Heat treatment is usually done with an oven and is good way to enhance the properties of certain materials. Usually heat treatment is better suited for smaller object since larger objects might require more expensive equipment. Heat processing consumes usually lot of energy.

Table 2: Processes that can be used for kevlar, CR and aerated concrete

	Processes								
	Joining			Shaping			Surface treatment		
	Adhesive flexible	Fasteners	Adhesive Rigid	Additive manufacturing	Machining	Sewing	Painting	Surface coating	Heat treatments
Kevlar						x			
Chloroprene rubber CR	x	x		x	x		x	x	
Aerated concrete			x		x		x	x	x

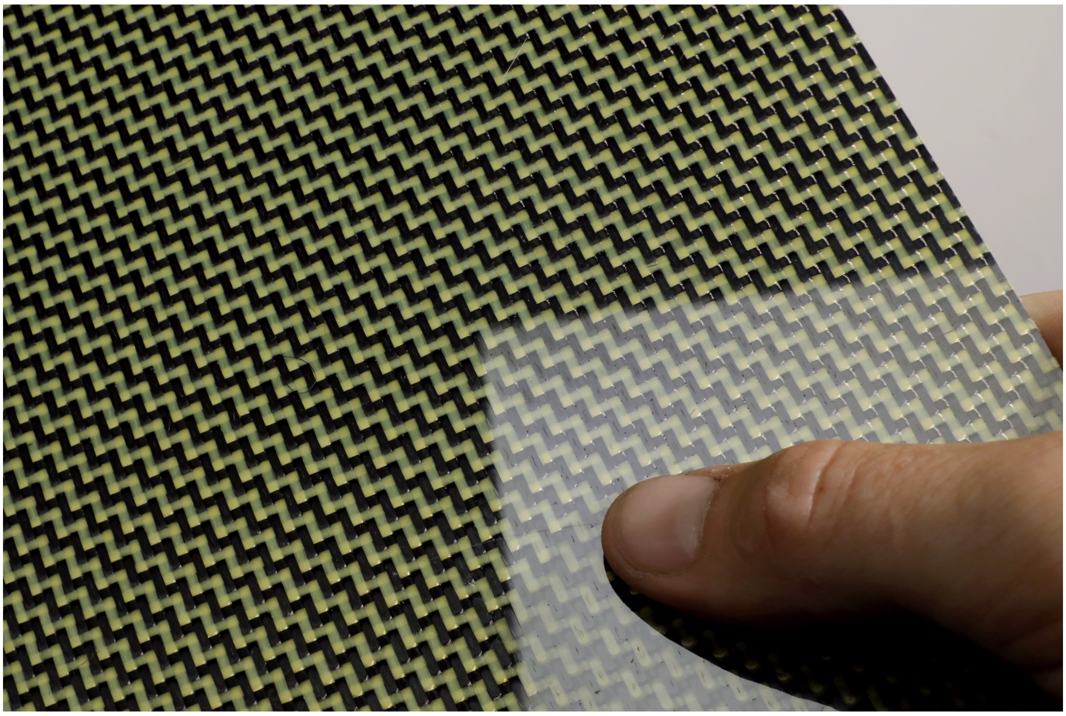

Figure 5: Laminated kevlar.

5.2.3

Bulletproof vests require a durable outer layer and impact absorbing layers woven inside it. Durable outer layer is usually made out of nylon which has good resistance against abrasion and tearing. The outer layer is tailored into correct shape and sewed together. Kevlar is polymerized, spinned and weaved into layers to create a flexible, yet impact-resistant material as the impact absorbing layer inside the nylon layer. The kevlar layers are laminated and stitched together using heat.