UNIVERSITY OF TWENTE.

# SMART ENVIRONMENTS PROJECT

## Documentation report

**Team 10: Force India**

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# Contents

## 0 Introduction

In this document a potential solution for harvesting wind in remote areas will be proposed. It will go in depth on how we plan to realize it and motivate our choices.

We set out to tackle the problem of powering climate sensors in remote places as this is a relatively unexplored area and is one way to help tackle climate change.

To realize this harvesting energy from a renewable source would be a requirement. We came up with a solution that harvests energy from wind. There already is a way to do that: windmills. However windmills are difficult to set up in remote areas, and disturb, or are dangerous for the wildlife.

We propose a more passive solution by using trees to harvest wind energy. The reasons why we chose to use trees to do this is because:

- Trees are available in most remote places
- Trees don't change too much; They are reliable
- Wind constantly affects trees
- Trees don't disturb the wildlife
- Trees are already in their place; no need to build something completely new

Specifically, our solution consists of wrapping one long rope 5 times around a tree, in such a way that the rope makes a star pattern when looked at from above. This rope is held up by a wooden ring with pulleys on the inside of the ring that the rope goes through. This rope is wrapped tightly around a dynamo at the ends of the rope (as denoted by the red rectangle in the diagram).

The idea then is that when the tree moves as a result of wind hitting it, the rope expands, and it gets this extra length from the extra rope wrapped around the dynamo. Then finally the dynamo spins and generates electrical energy. A weight is attached to the end of the rope so that the rope gets tightened again when the tree no longer pushes on it.

We will verify our results by hooking up a wind sensor and a voltage meter to this setup, and then graphing the voltage against the wind speed. This way we can visualize how much voltage this setup generates at different wind speeds.

This document will go in depth on all the research steps we went through to arrive at our final solution. It does this by first summarizing existing research done on climate change, second by discussing the problems found in the research, and third and finally the process of how we came up with our solution.

# 1 Literature review

## 1.1 Food handling practices and expiration dates: Consumers' perception of smart labels

A lot of food is wasted in households because people misinterpret the expiration labels on food packages. They throw away food, not because it has gone bad but because it has reached the expiration date, even though it might still be edible. Smart labels are labels that do not tell you an expiration date but tell you how the food feels when it has gone bad for example. There are even smart labels that contain sensors or indicators, these will tell you if the food has spoiled. However, a lot depends on whether the person trusts these labels or not.[1]

## 1.2 Planting Trees Won't Stop Climate Change

Nowadays there are a lot of initiatives to plant a lot of trees, because people believe that planting any tree, anywhere will help save the planet. Planting trees in places that are naturally treeless can destroy the ecosystems there. Planting a lot of trees that are not native will make a plantation, not a forest, that is often vulnerable to diseases. Planting a trillion trees is a very bad idea since, to plant all of them you'd have to plant them on grassland, grassland that is currently a better carbon sink than natural forests. Also if there are fires, the grass would release less carbon since they store it more underground. Planting trees in the wrong places could even worsen climate change and destroy wildlife.[2]

## 1.3 Food Production and Emissions of greenhouse gases

The food industry has a big impact on climate change, due to the cultivation, transport and packaging of products. In meat production the most important factor for GHG is the production of feed for the animals, whilst by vegetables the cultivation itself causes the biggest emission. The cooling of products in storage or during transportation also causes a big emission. But the most important polluter factor of food production is the waste of food. This happens during the cultivation, industry and retailing, but also a lot by the consumers. There are many ways to increase the GHG emissions in the food industry such as more efficient packaging (smaller volume/weight), reducing waste and better communication between all producers/consumers in the food production chain.[3]

## 1.4 Health effects of climate change

Because of climate change vulnerable people will have more problems such as heat strokes, because of the rising temperatures, or astmatic/ bronchitis problems due to the increase of forest fires or drought. Also diseases will spread more easily due to the warmth, mosquitoes, or fludings that cause unhygienic situations. Climate change impacts people's life in social, physical and environmental aspects of life.[4]

## 1.5 Climate change and forest fires

Although a lot of fires are caused by human activities, these are not the most dangerous fires to appear. They are most of the time more accessible and easier to extinguish. However fires caused by natural causes such as lightning cause lots of damage because these fires are detected later and the location is most of the time hard to reach. The occurrence of forest fires depends on vegetation, topography, weather, wind and drought. The consequences of the fires are deforestation and a decrease of the biodiversity of that area. Because there are less trees there will be less absorption of CO2, which will warm up the earth. But because of the increasing temperatures fires will occur more often, because of the drought and heat.[5]

## 1.6 Climate change impacts on marine ecosystems through the lens of the size spectrum

Climate change is a complex issue that can be looked at from multiple angles. This article goes over some numerical models that have been used to look at the impact of climate change, and then, by looking at the abundance-size spectrum, it offers an alternative conceptual model. This model can take an abundance of things into account that numerical models can not, yet it is still not widely used.[6]

## 1.7 Climate change impacts and adaptation in cities

Future urban planning requires a lot of decision making based around climate change. Whilst there are a small number of studies on cities in, mostly, OECD nations that are quite in depth regarding the cost of climate change risks in alternative scenarios, this type of research is still quite young. This review gives an assessment on the valuation and quantification of climate change risks at the city scale.[7]

## 1.8 Refugees, Migrants or Displaced People?

Climate Change Induced Displacement (CCID) has become more apparent over the past years and the recognition and protection of the people affected is still inadequate. The United Nations and the European Union have been very influential in shaping the debate around global warming, but there hasn't been much research on their responses to CCID. This analysis concluded that both organizations prefer to keep a status quo situation regarding the legal framework in which to solve the issue, but they differed in how they framed the movement of the people affected, as forced, voluntary, neither or both. How do governments deal with and respond to these displaced people and what possibilities do they have at their disposal? This work brings an often unheard of issue that needs more attention forward.[8]

### 1.9 Consumer neuroscience to inform consumers - physiological methods to identify attitude formation related to over-consumption and environmental damage

The main topics of the last few decades have been: climate change, the need for efficient and environment-friendly energy, health-related issues (obesity and addictions). Firstly, the rise in intensity of the weather conditions does not only represent a life-threatening danger to some civilizations, but it will also influence individual attitudes and decision-making. Second of all, the EU aims to cut the annual primary energy consumption, which will affect the global industry as well as the consumption behaviour of every singular user. Ultimately, according to the WHO the worldwide obesity has doubled since 1980. The only solution to this unpleasant scenario is to get active now to guarantee everyone a better future.[9]

## 1.10 Accounting for the Impact of Food Waste on Water Resources and Climate Change

Feeding all the 9 billion inhabitants of the world by 2050 will be extremely challenging, even more complicated by uncertainties and damaging climate changes. One of the main causes of this deficiency is the unequal distribution of food: overconsumption and wastage in some countries, hunger and malnutrition in others. The Earth's resources have been consumed faster and faster than they can be replenished and are destroying the supply system. In order to avoid that, food is classified as: "avoidable waste", "possible avoidable waste", "unavoidable food waste". The solution key is reducing food waste to make a significant contribution to addressing the water and carbon footprints.[10]

## 1.11 Climate change, environmental degradation and armed conflict

Climate change influences freshwater availability, the productive capacity of soil and the patterns of human settlement. All of this will have a big effect on the increase of violent conflict caused by the scarcity of resources (e.g. freshwater, arable land). It involves the relationship between population density and conflict: in large and densely populated cities there are more chances for organizing conflicts and they also represent strategic targets. This also means that economic, political and social factors determine how the different countries can handle the resources management: wealthy and democratic countries are likely to be more able to adapt themselves to resource scarcity and to mitigate possible conflicts.[11]

## 1.12 Weather extremes

Recently there have been a lot more extreme weather events, from heatwaves to heavy rainfall. New heat records are set and millions of people die from flooding. If the temperature rises 1 °C the air will contain 7% more water, which can rain down. This 7% increase of moisture in the air also means more latent energy, which causes storms such as hurricanes. If there was no climate change, the number of extremes should be constant but the amount of extreme heat waves is increasing fast. Further research should be done into why some years the temperature records exceed the margin by so much.[12]

## 1.13 Our future as a species

A professor emeritus in economics discusses how humanity has only relatively recently (since the Holocene) been able to rely on agriculture because of a warmer climate compared to earlier ages. In addition, he argues that past societies have collapsed in part due to climate change, and that we might meet a similar fate, with agriculture becoming hard or impossible due to unfavourable conditions for crops to grow in (e.g. loss of pollinators, temperature changes, droughts or floods). Finally, he mentions that in the long run, having some degree of de-industrialisation is inevitable, and proposes some policies to make this process more gradual.[13]

## 1.14 Climate change and human health

The U.S. Global Change Research Program investigates how climate change affects human health in the United States. It is found that climate change increases the number of yearly deaths due to the effects of heat or cold, since average temperature increases and local temperature can show greater extremes. Furthermore, increased air pollution (ground-level Ozone and fine particles) and aeroallergen levels (due plant growth from CO2 level increase) negatively affect human cardiovascular and respiratory systems, while an increase in extreme events (such as heatwaves, tornadoes, hurricanes and floods) may put human thriving at risk in general.

Continuing on, climate change impacts the distribution, prevalence and seasonality of vector-borne diseases (such as malaria from mosquitoes), however it is hard to predict how exactly this will affect human health. Next, both fresh and marine waters are expected to expose more humans to illness from contaminants such as bacteria, viruses, algae toxins (from increased spread) and chemicals from human activity.

In addition, food production is impacted by rising global temperatures and changes in weather patterns and extreme events, leading to contamination, spoilage and complication of distribution to people. Also, more CO2 in the atmosphere increases growth and carbohydrate synthesis in some plants, yet lowers protein and mineral levels in, among others, wheat, potatoes and rice, potentially affecting human health negatively.

Penultimately, the mental health of individuals is impacted, potentially leading to anxiety, depression, PTSD, or suicidality. These originate from individuals' and communities' experience of and response to climate change. These mental health effects usually go hand in hand with social and environmental stressors, such as physical health. Finally, some groups are more likely to experience health effects from climate change than others, such as minorities, the poor, children, pregnant women and the disabled.[14]

## 1.15 Ocean acidification

Scientists from the Max Planck Institute for Meteorology have discovered hints that an increased oceanic pH due to more CO2 absorption could lead to less dimethyl-sulfide emission into the air by phytoplankton ecosystems. Dimethyl-sulfide is important for the seeding of clouds, so lower levels of it could mean fewer clouds reflecting solar energy, leading to a hotter low atmosphere. However, more data from (sub)tropical areas is required to verify.[15]

## 1.16 What makes CO2 a "greenhouse gas"?

A climate scientist at Columbia University explains the mechanism by which CO2 "traps heat": Sunlight that reaches the surface of the Earth is re-emitted as infrared (IR) light, which we feel as heat. Normally this IR wave would escape into space, but it just so happens that the geometries and composition of, for instance, CO2 and methane allow them to absorb such light, and re-emit it in all directions. This means that half of the IR light does in fact disappear into space, while the other half travels back to the surface, thereby adding heat to the Earth. This is in contrast to the behaviour of, say, O2 and N2, which don't absorb IR light. There exist natural "carbon sinks" that remove CO2 from the atmosphere and store it in the Earth. However, they cannot respond fast enough to our current interruption of the carbon cycle.[16]

## 1.17 Impact of global warming on plants, and keeping track of biodiversity of plants

Analysis on the impact of global warming on plants. Specifically the researchers used image processing on pictures of the leaves of different plants, to see what their shape and size is. This method makes it possible to distinguish between different plant species since they differ in size, shape and patterns. This in turn makes it possible to keep a record of how many plants of a plant species are in a given area, or an indication of how good the biodiversity is, and see how global warming has affected plants.

This could be a good inspiration for a smart environment that would keep track of something biodiversity related with different sensors. for example hooking up O2/CO2 sensors to an Arduino to keep track of how many plants there are within a given area.[17]

## 1.18 Awareness of general public with regard to global warming

Research paper on how informed the general public is about global warming. Questions that reveal how important they think it is and how likely they think it is that global warming will affect them in their lifetime. The paper shows that people think global warming is somewhat likely to impact them in the future. This is compared to how likely they thought other events will impact them one day such as: car accidents, violent crime, cancer and heart disease. Important to note is that global warming isn't very high on this list. The people questioned might be not aware about global warming, misinformed or just think that it isn't as impactful. This paper is from 1998, so the perspective may have changed during the last 23 years. We could make a smart environment with the purpose of raising awareness.[18]

## 1.19 Psychological effects of global warming: increase in violence

A research paper about how global warming appears to cause an increase in violence, be it through direct effects of global warming or indirect. A few of examples of things that seem to cause an increase in violence are things such as: heat, climate refugees, drought, flooding, food scarcity and other ecological problems that result from global warming. The paper also shows how these things can have chain reactions that lead to even more violence.[19]

## 1.20 The unexpected ways climate change harms your health

Climate change affects our health and has lots of consequences. It represents a threat for contaminations into the food we eat and the water we drink: high temperature in the oceans means mercury accumulation in seafood and flooding also raises chances for foodborne illnesses, at the same time increasing risk of bacteria and pathogens. Environment disasters compromise mental health, especially those populations considered already-vulnerable. The air we breathe is dirty. We are at stake if we do not act now, every single change can determine a disaster.[20]

## 2 Identification of general problems and challenges

Among the main problems and challenges that stood out in the publications above are:

- Extreme weather conditions
- Waste heat/energy in the household and everyday life
- Inequality in the distribution of food
- Food waste in commercial and domestic settings
- Deforestation due to forest fires
- Human overconsumption
- Overpopulation and population pressure
- Armed conflicts over limited resources in the future
- Human health consequences from infected or polluted water
- Human health consequences from change in quality of agricultural produce

## 3 Identification of relevant problems

Below are 5 more urgent problems that, according to us, have not been addressed well:

- Conservation of biodiversity
- Emissions from the production of vegetables and feed for animals
- Further education and awareness about climate change
- (Re)planting forests and other flora
- Energy production and storage

## 4 Problem selection and motivation

The problem from above that lies within our ambitions and interest most is the final entry in the list. More specifically, **Creating a novel technique for energy harvesting.**

Currently, it is difficult to harvest or store energy in remote places, since there is no access to the usual systems and grids we are used to in modern society. A specific field in which this is a relevant problem is the deployment of sensors that keep track of the environment in the wilderness. Such tracking is of value for several reasons, among others the monitoring of the "health" of an ecosystem, or the early detection of forest fires.

# 5 Potential solutions

Among the most noteworthy solutions conceived for the challenge posed above were:

## 5.1 Smart ball

The ball would be a new and green energy source which can be available for and used by everyone. It will generate energy whilst bouncing or being squeezed. This energy could be used for small things such as charging your phone. You could use it while sporting or as a toy.

## 5.2 Smart Coasters

Whenever you set down and lift your cup it will create energy by a mechanism with springs. With the smart coaster you can make energy easily at homes, in restaurants or in bars, which can provide a green source of energy.

## 5.3 Boxing ball (anger to energy)

Similar concept as the ball. When you hit it, it will produce energy by converting the force into electrical energy. And you can even get rid of your anger. This energy could be used to power machines in gyms or at home, which could be a new and conscious energy source.

## 5.4 Shower

Special shower tiles will generate energy from the hot water while you shower. The leftover heat is converted into electrical energy. If every house has a shower like this lots of green energy will be produced.

## 5.5 Gravity energy generator

When it rains a basin on top of a building will hold the water. When you need energy you let this water flow down, the gravity of the water will move to a hydroelectric generator, which will produce energy when you need it. In this way you can have access to green energy all the time

## 5.6 Tree movement generator

An installation which can generate energy from tree movements due to the wind. The generator is connected with wires to the top of the tree, where the tree moves the most. With some sort of turbine which wraps and unwraps the rope as the tree is moving further or closer to the generator. This energy could be used in fire detector sensors in forests.

# 6 End solution

## 6.1 Solution selection & Provisional modulation

We chose to go with the tree movement generator idea. This is because it is currently a problem to provide fire detector sensors in forests with energy. It's the idea that called to us the most because it is a problem that lots of people have tried to solve but nobody found the solution yet. We like this challenge and want to give it a go. We also figured that some of our other solutions might be very hard to design and the energy that they would provide would not have a purpose. With the tree movement generator the energy that is generated would have a purpose and wouldn't go to waste. Furthermore we also thought that this idea is most suitable for the final demonstration.

To achieve a working prototype of this concept, the following should be put into action:

***Research***

- The working of Piezo-electricity [Sem, Olivier]
- Tree movement and how much power could potentially be harvested [Marta]
- What sensors are useful to power; In particular a sensor for fire detection [Demi]
- Operation and usage of generators/dynamos [Sem, Olivier]
- Suitable batteries for the system [Janine]
- Material costs [Arthur]

***Design***

- Electronic design [Sem, Olivier]
- Aerodynamic and tree prop design [Marta, Demi]
- Mechanical design [Janine, Arthur]
- List materials needed [ALL, according to their part]
- Order said materials [Olivier]
- Physically craft a prototype of the design [ALL, according to their part]

***Testing and evaluation***

- Decide on what to test and evaluate, and how to do so [ALL]
- Obtain data on windspeed [Demi, Janine, Marta, Sem]
- Obtain data on generated power [Demi, Marta, Olivier]
- Process data on windspeed, and draw conclusion [Sem]
- Process data on generated power, and draw conclusion [Olivier]

## 6.2 A rough design

To clarify, some rough sketches of the end solution are presented below. Some annotation is still needed. Note that the device has two "flavours" to be considered: One with a dynamo, and another with piezo-electric generators.

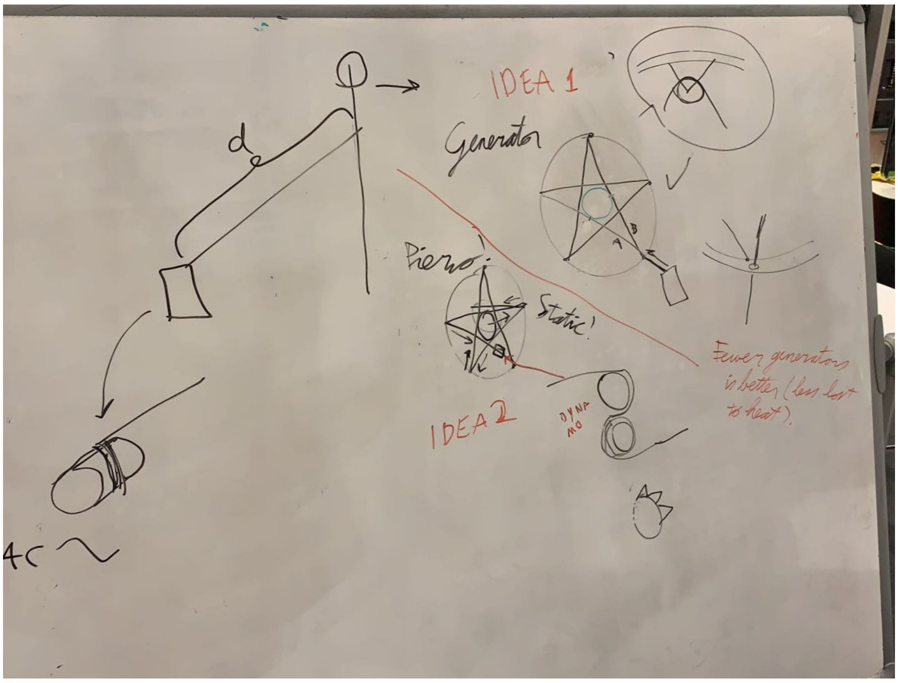


Figure 1: Rough sketch for the device and its two variants. Note the pulleys to guide the ropes on the inside of the ring.

The concept is this: The device that attaches to the tree generates a voltage, which is used to charge a battery, which in turn powers an Arduino that takes input from a sensor and transmits data. Let us first consider the two device flavours discussed above:

***Dynamo approach*** One way to harvest energy involves using a dynamo. The idea would come down to having a tree or stick in a construction of one long rope wrapped around it. At the end of this rope would be a dynamo with rope wrapped around it, and a counterweight to have the dynamo "wind back". When the tree or stick moves, thanks to wind, the rope will have to be extended and this rotates the dynamo, which in turn generates electricity.

***Piezo-electric approach*** For this idea we would have piezoelectric material in places where the rope moves along, then the pressure of the rope on this material would cause the piezoelectric material to generate electricity, and this could be harvested.
The rope itself could maybe even be made out of piezoelectric material, but this might be very costly to make. This rope could maybe even have a dual purpose as a wire, which also solves the problem of having to transport the generated electricity from the piezoelectric material. Now how could we make a prototype using this solution? Pre-made piezo elements for the arduino that are specifically designed to generate electricity seem hard to find or non-existent.
A possible way of generating piezoelectricity with an arduino we thought

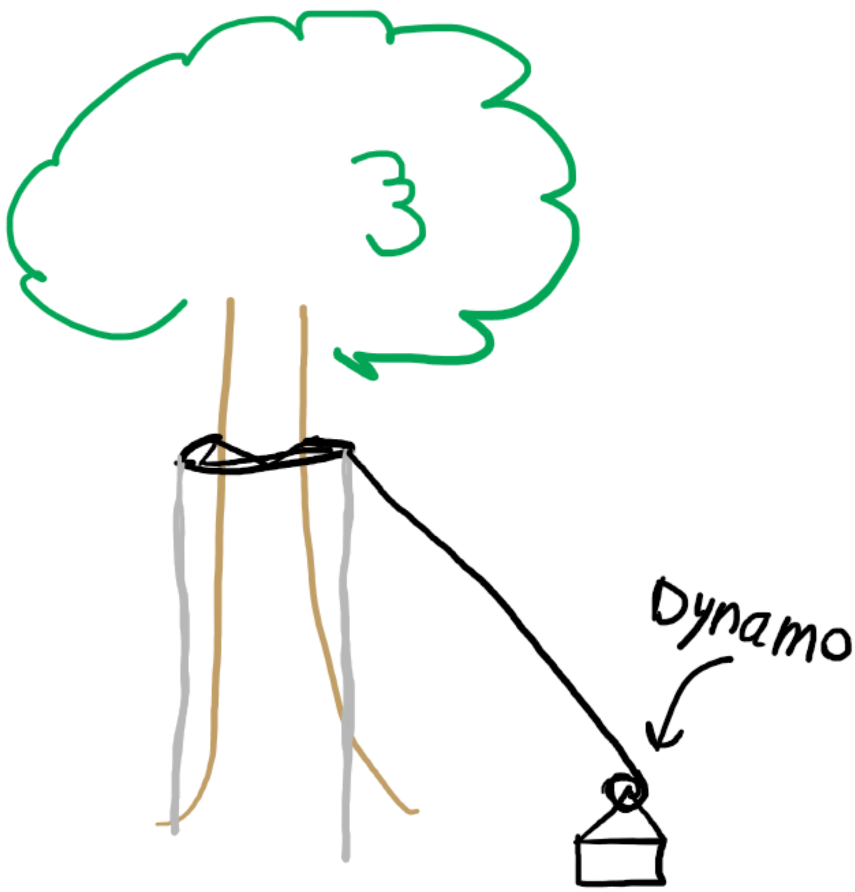


Figure 2: Another (side-view) sketch of the device, this time the dynamo variant.

of is by reverse engineering a piezo buzzer or a piezo speaker. A piezo buzzer/speaker works by converting electricity into vibrations, but we could also use the piezo material to do the opposite: converting vibrations into electrical energy. We wouldn't have to do any actual reverse engineering as this is a property of piezoelectric materials; they can facilitate this process in both ways. In conclusion this would only require removing the outer part of the buzzer that protects the piezoelectric material. However, will have to experiment with how well this works.

In essence both the piezo and the dynamo harvest energy from mechanical stress applied to the system. There are a few differences though:

- The system has an end attachment point (dynamo) vs all the rope is nicely contained within the perimeter of the circle (piezo).
- They both generate electricity, but likely in different amounts and efficiency. This will have to be researched further.

Next, let us look into some potential ***Sensors*** to truly make this a *smart system*: We can connect our power generating system to power all different kinds of sensors. Sensors which can detect fires, or other natural disasters, or sensors which can gather data about the changes in the environment. Depending on where we want to implement the energy generators we can choose a suitable sensor.

If we place the system in the forest following the original energy harvesting idea from treemovement, fire detecting sensors or data processors about biodiversity or soil composition could be useful. Or if we place the generators at sea we can use sensors that can detect earthquakes to be able to warn people in time for tsunamis and earthquakes. Close to water reservoirs we could use it to power water pollution detectors.

Most sensors can be made with the using the arduino as a base. The arduino needs 7 to 12 V and 500mA to 1 A to work optimally.

In order to make a fire detector sensor you need an arduino in combination with a flame sensor. The flame sensor detects the wavelength between 760 and 1100 nm and can thereby calculate the temperature a body. In this way it is also able to identify fires. For this sensor you need an operating voltage between 3,3 and 5 V.

Another sensor we could make is a sensor which detects the water quality, looking at pH, temperature, and turbidity of the water. This sensor could share the data for researchers or environmental protection organizations.

## 6.3 Power prediction

In light of the design above, let us make a theoretical prediction of the power it will generate. Consider the tree in the system that undergoes a small deviation from its initial state $u$. Then, for small $u$, the length of rope it will "pull in" from the dynamo is, by the Pythagorean theorem,

$$\left(\frac{l_1}{2}\right)^2 = \left(\frac{l_0}{2}\right)^2 + u^2 \tag{1}$$

Where $l_0$ is the original rope length when the tree was in its initial state, and $l_1$ is the new rope length after deviation $u$. So,

$$l_1 = \sqrt{l_0^2 + 4u^2} \tag{2}$$

And the length of rope taken from the dynamo is

$$l_1 - l_0 = \sqrt{l_0^2 + 4u^2} - l_0 \tag{3}$$

The counterweight on the other side of said dynamo is lifted vertically, so the work done by the tree to lift it has to be

$$W = (F_{EM}+F_g)\Delta s = (F_{EM}+F_g)(l_1-l_0) = (F_{EM}+F_g)(\sqrt{l_0^2 + 4u^2}-l_0) \tag{4}$$

With $F_{EM}$ an electromagnetic drag force caused by the dynamo, and $F_g$ the gravitaional force. The work the tree actually does due to the wind is

$$W_T = F_u u \tag{5}$$

Where $F_u$ is the force along the same direction as the deviation of the tree. Due to conservation of energy by Noether's theorem, it must hold that

$$W_T - W_{EM} - W_g = 0 \tag{6}$$

And thus, we can write for the work done on the dynamo

$$W_{EM} = F_u u - F_g(\sqrt{l_0^2 + 4u^2} - l_0) \tag{7}$$

Now model the force on the tree as the difference between an aerodynamic force and its internal elastic force:

$$W_{EM} = \frac{1}{2} C_D \rho v^2 A u - k u^2 - mg(\sqrt{l_0^2 + 4u^2} - l_0) \tag{8}$$

As such the electrical power harvested will be $\frac{dW_{EM}}{dt}$. Note that, for small $u$, the expression above only has a single variable that depend on time: $u$ itself. $v$ does not depend on time, since we assume the wind speed to be constant. Additionally considering the case where $u$ is small enough to be negligible compared to $l_0$, the derivative becomes

$$\frac{dW_{EM}}{dt} = \frac{1}{2} C_D \rho v^2 A \frac{d(u(t))}{dt} - k \frac{d(u^2(t))}{dt} \tag{9}$$

Interesting to see now is that $\frac{d(u(t))}{dt}$ is simply the *velocity* of the tree. Using the product rule, the expression changes into

$$\frac{dW_{EM}}{dt} = \frac{1}{2} C_D \rho v^2 A \frac{d(u(t))}{dt} - 2ku \frac{d(u(t))}{dt} \tag{10}$$

Now let us assume the tree sways in the wind in a sinusoidal fashion at a frequency of 0.5 Hz. This means it will have an average velocity[1] $v_{avg} = 2/pi^2 = 0.2026$ m/s. Let us also assume that the maximum deviation $u = 10$ cm, $C_D = 1.2$, $\rho_{air} = 1.225 kg/m^3$, $v_{wind} = 5$ m/s, $A = 6m^2$ and $k = 7000$ N/m. This yields a prediction for the power of

$$P_{EM} = -261.30\ W \tag{11}$$

Meaning this sytem will sap energy at an alarming rate...

[1] https://socratic.org/questions/what-is-the-average-value-of-a-function-sin-x-on-the-interval-0-pi

## 7 Methodology

This methodology is heavily subject to change, but for now we can at least entail two plans of graduating difficulty; A **basic** plan and an **advanced** plan for a prototype setup, along with relevant variables to measure.

***The basic plan***
Roughly, the basic plan will entail obtaining power from the tree via the dynamo[2] system described above, which will be inferred by measuring the voltage over a load resistor attached to the output. This power will be compared to the free-stream wind velocity that pushes the tree over in some direction, which will be measured with a wind sensor attached to an Arduino. The ideal situation would be to power this very Arduino by the power generated, but it remains to be seen whether this is feasible or not. The worst case scenario would feature the Arduino being powered externally, while ways to increase power output are considered. Among the required materials for a (scale) prototype of this approach (and their costs) are

- Rope; Any quality rope for many lengths **(∼ 5 €)**
- Wooden ring; Used to attach 4 pulleys on to, so that the rope can go around. **(23 €)**
- Wooden planks; Used to support the wooden ring, so that it can stay in the air. Also used to make compartments for the electronics and batteries. **(No cost, found scrap)**
- Flag; Used to catch wind. In our particular case we used Dutch flags. **(8 €)**
- PVC tubes; Used as a scale model version of the tree, because it is strong but bendable. **(1.50 €)**
- Plastic bucket; Used as a sturdy ground to put the PVC tubes in. (∼ **2** €)
- Cement; Used to fill the bucket with so that the PVC tubes stays in its place. (∼ **6** €)
- Voltage regulator for Arduino; This might be handy **(9.60 €)**
- ~~The ALD EH300; to rectify the AC output of the dynamo.~~ This was impossible to find, so we ended up building our own rectifier.
- 4x Schottky diodes; used to rectify the AC output of the dynamo. (Turns the AC into DC in our circuit) (**2.52** €)
- Dynamo; Used to power the sensor. We ended up using one that is normally used for bikes. Another good choice would be the SON 28, which has been used before[21] **(4.09 €)**
- Crododile wires; Used to connect the dynamo to the rest of the circuit. **(Negligible cost, already in Arduino kit)**
- Arduino UNO; The brains behind the sensors **(Negligible cost, already in Arduino kit)**

[2] As we've recently learnt, a "dynamo" that generates AC is actually referred to as an alternator.

- LEDs to incorporate into the circuit to indicate if the battery is charging **(Negligible cost, already in Arduino kit)**
- Voltmeter; Can be lent.
- Wind sensor; It's too expensive to buy one within our budget. Instead we will make one ourselves with an LDR and Arduino.
- LDR; Used to make a wind sensor **(Negligible cost, already in Arduino kit)**
- Cardboard; Used to make the wind sensor with. **(Negligible cost, can just use an old box)**
- Fidget spinner; Used as a way to rotate the wind sensor, just a ball bearing also would have worked. **(Had this lying around, no cost)**

*Note as of 30/01/2022:* The final cost of the project, including shipping, came out to be around 110 €. Also, in order to power the Arduino, 8 rechargeable AA batteries were purchased.

***The advanced plan***
The advanced plan will flow naturally from the ideal case presented in the last subsection, except that additional types of sensors (as mentioned in subsection 6.2) will be considered for use *and* such a sensor will be powered by a battery that is charged by the system. Concretely, we can add

- 9V Rechargable battery; To power the Arduino and charged by the dynamo **($\sim 9-20$ €)**

to the materials list.

***Data collection***
The most crucial parameter to calculate from a prototype of this device is its power output. In both device variants, this can be done by attaching an (impedance matched) load resistor to it and measuring the voltage over it to calculate the maximum power output $P = V^2R$. This measurement is rather crucial for another reason, namely to see if the output voltage of the device would be compatible with the Arduino, and, if not, what needs to be done to make this voltage appropriate.

***Data processing and analysis***
An interesting thing to look at in data processing could be the measured power vs. the theoretically available power from the system. This means some in-depth analysis, but it should be doable. Dividing these two parameters yields the efficiency of the device, which could be very useful to compare it to, say, more traditional energy production means. Additionally, the output power could be measured alongside tree deflection or local (free stream) wind velocity to model power as a function of either of these. Finally, this same power could be integrated with respect to time to find the total energy generated, and by this for what timespan the Arduino and including sensors could be powered by the battery.

# 8 Validation

## 8.1 Measuring wind speed

As discussed just above, it is of interest to know how much power is generated at certain wind speeds. To obtain this information, we had to use a wind sensor. However, our restricted budget did not allow us to purchase one, nor were we able to borrow one. Therefore, we came up with our own wind sensor solution, which works by setting up an LDR with an 18-centimeter-diameter cardboard disk spinning over it, offset from the centre. This disk has a hole in it, meaning that as it rotates, the LDR will register light and dark periodically. Additionally, The cardboard piece has three cardboard fins on it that catch wind. This whole element rotates on a fidget spinner. The idea then is to register with an arduino program when the hole is above the LDR, and store that in a variable which we print to the serial monitor. This way we can keep track of how many rotations the cardboard circle has done. The exact code used in this experiment can be found on page 27.

If we then know the total rotations, and the time in seconds it took to rotate that amount we can then calculate the wind speed. We calculate this as follows: For one revolution of the disk with diameter $d$, we know that

$$\text{rev/h} = \text{rev/s} * 3600 = \frac{3600 * \text{Rotations}}{t} \tag{12}$$

And so

$$v_{wind} = \frac{3600 * \text{Rotations}}{t} * \pi d \tag{13}$$

with $d$ in km and $t$ in h.

**In conducting the wind speed experiment**, Our setup consisted of putting a leaf blower at two different distances from the self made wind speed sensor mentioned above. This way we simulated two different wind speeds, which can be easily replicated for the power generation experiment.

Before we started each round of wind speed measurements we measured the distance between the leaf blower and the wind sensor, so that we can then use the exact same distance in the power generation experiment, and get the same wind speed.

Everytime we did a reading the steps were as follows:

1. Reset Arduino program, this way the rotation counter is at zero again.
2. Start a timer of 30 seconds and the leaf blower at the same time.
3. When the timer hits 30 seconds, turn off the leaf blower and stop the Arduino program.
4. Write down the amount of rotations measured by the wind sensor.

After getting at least three somewhat reliable readings, we repeated this whole process but with the leaf blower at a different distance. For the first round of measurement the distance was 1.07 meters, and for the second the distance was 1.77 meters. The results of this experiment can be found in section 9 of this report, while the Arduino code resides in appendix A.

## 8.2 Measuring generated power

In order to measure the power this whole system generates, let us first consider how it was set up electrically: As can be see, a bridge rectifier (in our case

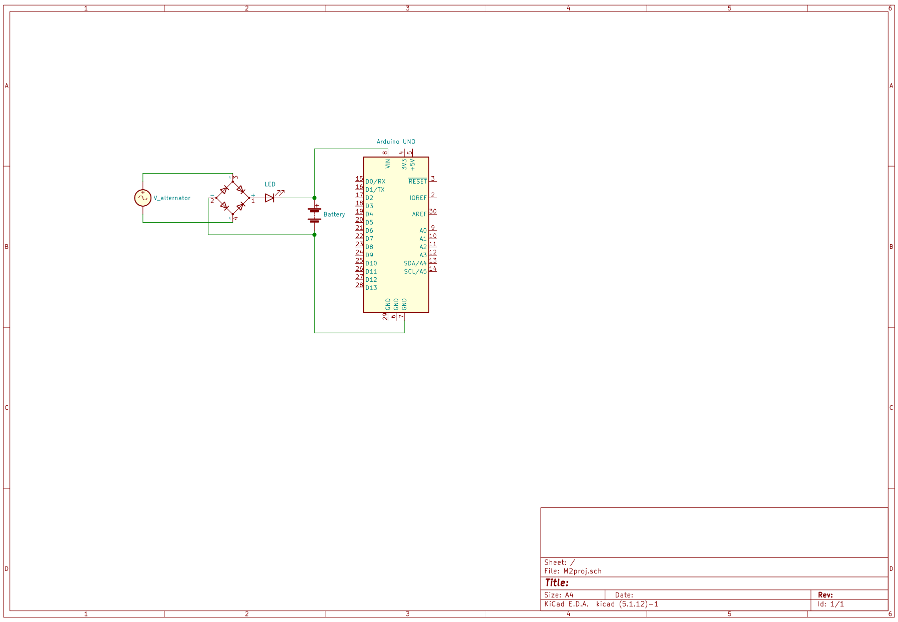


Figure 3: Schematic of the electronics of the system.

constructed with Schottky diodes) turns the AC voltage from the alternator into DC to charge the battery, which powers the Arduino. The LED in the circuit functions both as an indicator to verify that the system is generating electricity, and to prevent current from flowing from the battery back into the rectifier. This circuit was built and connected to the rest of the system as shown below.

Additionally, the rectifier was tested independently using a function generator and oscilloscope.

Something that became quite obvious as the wheel attached to the alternator was turned by hand for testing purposes, was that this system generates very little power, requiring more angular velocity than the tree could ever yield to have a single LED turn on. A low-power system was expected, but this qualitative result was disappointing.

Figure 4: The finished build of the system.

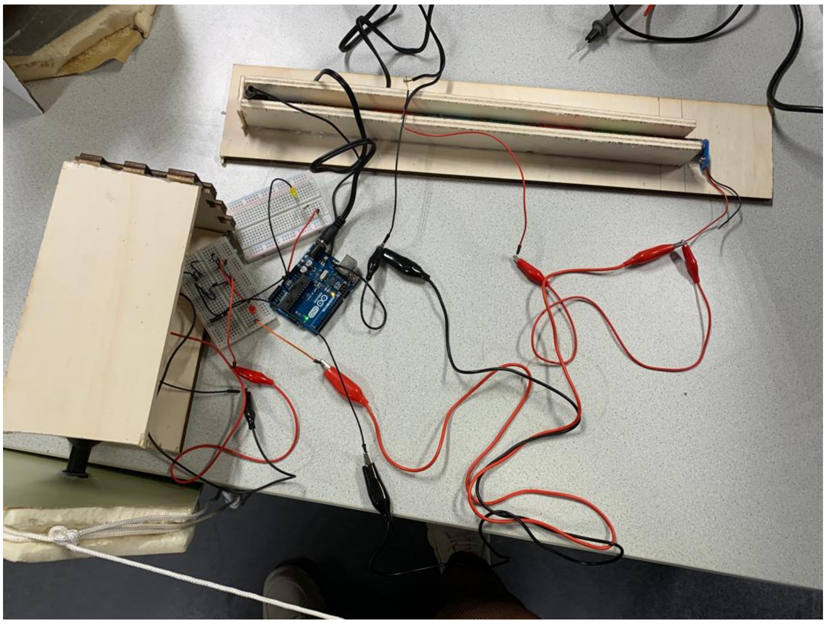

Figure 5: The electronics beloning to the system, with alternator and recitfying circuit on the left, the Arduino in the middle, and a hand-made battery bank with eight AA batteries at the top.

# 9 Results and conclusion

## 9.1 Results

First come the results of the measurements with the wind sensor:

**Distance from the wind sensor: 1.07 m**

| Rotations (#) | time (s) | R/s (#/s) | wind speed (km/h) |
|---|---|---|---|
| 349 | 30 | 11.63 | 23.65 |
| 388 | 30 | 12.93 | 26.29 |

Table 1: Wind speed measurements at a distance of 1.07 m from leaf blower airflow.

**Distance from the wind sensor: 1.77 m**

| Rotations (#) | time (s) | R/s (#/s) | wind speed (km/h) |
|---|---|---|---|
| 236 | 31 | 7.6 | 15.45 |
| 225 | 32 | 7 | 14.23 |
| 191 | 29 | 6.58 | 13.38 |
| 206 | 31 | 6.64 | 13.50 |
| 205 | 32 | 6.4 | 13.01 |

Table 2: Wind speed measurements at a distance of 1.77 m from leaf blower airflow.

Next in line are the outcomes of the rectifier test. From the raw data (which has been excluded from this report for brevity), we obtain that the maximum and minimum output voltages were $V_{min} = -1.36000$ V & $V_{max} = -0.56000$ V, respectively. Beyond this, the rectifier circuit was also tested by connecting

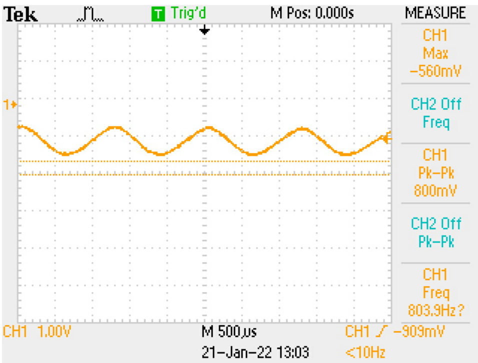


Figure 6: Scope image of the DC output signal of the rectifier circuit with a 5V peak-to-peak AC input. Note that all measured voltages are *negative* in the raw data; a vertical offset was used to get the signal above the scope zero line. The voltages being negative is no problem, the rectifier is working properly as long as it transforms the input voltage (which switches between negative and positive) to either of those signs.

the purchased alternator to it and turning it directly by hand. Quite a serious effort was required to light an LED this way, although less so than mentioned in the previous section, where the wheel was attached.

We were unable to measure the power generator by our tree movement generator because it was extremely low. We can however make an estimate based on other findings. The system could not power a single led. We did test how fast the dynamo would have to spin before it could power it by spinning it by hand. Based on this, we estimate the value to be in between 0.01 and 0.001 Volt. Using the formula $P = V^2/R$, with R the internal resistance of the battery, which is approximately 0.1 ohm for an AA battery.
A worst-case voltage of 0.001 V was estimated, and a best case of 0.01 V.

| V (Volt) | R (Ω) | P (Watt) |
|---|---|---|
| 0.01 | 0.1 | 0.001 |
| 0.005 | 0.1 | 0.00025 |
| 0.001 | 0.1 | 0.00001 |

Table 3: Estimations for the power generated by the total system.

The experiment we based our project on managed to get 0.00176 J/s. When we compare this to our finding we see that in the best case scenario we would still come 0.0076 joule/s short. In a more likely scenario we would have probably measured even less and thus come more short. However these are just speculations. Reasons for this shortcoming will be further discussed in the discussion.

## 9.2 On measurement errors

No measurement is of any value without an indication of its error, so we shall discuss this point briefly regarding the measurements above. For the wind sensor, there were two sources of error: Error on amount of rotations, and error on time. The prior is estimated as follows:

- Sometimes the wind sensor rotated backwards, or did not make a full rotation. This then gives a margin of error on the amount of rotations. This didn't happen that often. Estimated margin of error as a result is: +5%
- The Arduino program isn't flawless. The program seemed to count double rotations sometimes. Estimated margin of error thanks to this is: +15%
- The LDR wasn't located in a fully dark place, this might have had some small light interference as a result. Thus the program might have detected more rotations than in reality. Estimated margin of error as a result is: +5%

Another aspect to consider in regard to the amount of rotations is the fact that the time between readings on the arduino program is 10ms, and that the program adds a 10ms delay when a rotation is detected. This adds up to 20ms, which means that the maximum rotations per second this setup can measure is: 1000/ 20 = 50 RPS. This didn't matter fortunately since the RPS values were all a considerable amount below 50.

As for the the error on time, there are three factors to consider:

- Reaction time with stopping the serial print.

- Reaction time with stopping the leaf blower
- The time to stop the two activities mentioned above The margin of error on time is mainly because reaction speed is involved. Both stopping the arduino readings and the leaf blower take some time and are not done exactly at the same time. We estimate the reaction time and the time to stop to cause a maximum of 2s difference between stopping the program and the leaf blower ending. The margin of error would then be 2/30 * 100 = 6.66%

From all this, we come to a total estimated error of 5 + 15 + 5 + 6.66 = 31.66% , which has a quite considerable impact on the reliability of these measurements.

Now concerning the rectifier measurement, it is more limited thanks to the use of a professional Tektronix oscilloscope, which limits the error to a degree that is not of concern.

## 9.3 Conclusion

We have constructed the tree movement generator with only minor alterations to our original plan. The wind speeds of the leaf blower were measured and it's inaccuracies, so we would know the wind speed needed for the energy generated by the device. There is however, a big margin of error here which will have to be taken into account. We also tested the rectifier circuit with professional equipment, giving more accurate measurements than the wind sensor.

The whole system in inself worked as well. When we moved the tree, the rope would get pulled and the dynamo started rotating. However the power that was generated was qualitatively observed to be extremely low. We were unable to measure the power generated but there was some power generated. We partly did our advanced plan, however when we attached the rechargeable batteries to our system we immediately saw that it would not be enough to power a sensor.

## 9.4 Discussion

The aim of the project was not completely achieved. The partial failure of this experiment was most likely due to the budget. The dynamo was not good enough for this application. It had only a few poles, meaning it's conversion from movement to electricity was quite inefficient. We also had the problem that due to the voltage transformer being extremely small it might have broken during soldering. This made charging the battery confusing. We learned the valuable lesson here to look at the size of electrical components before ordering. The last point of discussion is our ring construction. The rope construction in itself was good, however it was not attached to anything and stood loose on the ground. This caused losses of rope motion.
Finally, the theoretically predicted value for the power generated by the system is beyond unbelievable, being, in fact, negative. It is not clear yet whether this is due to incorrect assumptions for values or an incorrect derivation on the whole; Future work will have to show this.

# Appendices

## A Arduino code for the wind sensor

```
    // Windspeed sensor code by Sem Bakker (2771020) for Team 10:
Force India, Smart Environments Project

int rotationCounter; // keeps track of amount of rotations
int lightMeasureMargin = 25;  // specify the difference between the
two light values


void setup() {
  Serial.begin(9600); // start the debug serial
}

void loop() {
  int lightValue = analogRead(A0);
  delay(10);
  int lightValue2 = analogRead(A0);

  if (lightValue2 < (lightValue - lightMeasureMargin) || lightValue2
> (lightValue + lightMeasureMargin)) {
    // if the difference between values is big enough, then a rotation
has happened
    rotationCounter += 1;
    delay(10); // add a delay so that there are no doubles
  }
  Serial.println(rotationCounter); // print the rotationCounter
}
```

This code compares the two light values of the LDR separated by a short interval of time, in this case 10ms. If the difference between these values is great enough it can then be concluded that the hole is above the LDR, the program then adds 1 to the rotation counter. It prints this rotation value to the serial monitor.

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